AD-A093 293 NETWORK ANALYSIS CORP VIENNA VA F/G 17/2
NATIONAL AIRSPACE DATA INTERCHANGE NETWORK (NADIN) COMMUNICATIO--ETC(U)
NOV 80 DOT-FA79WA-4355
UNCLASSIFIED NAC/FR-303A/01 FAA-RD-80-128 NL

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Report No. FAA-RD-80-128

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NATIONAL AIRSPACE DATA INTERCHANGE NETWORK (NADIN) COMMUNICATIONS SUPPORT FOR FLIGHT SERVICE AUTOMATION SYSTEM

AD A093293

Network Analysis Corporation
301 Tower Building
Vienna, VA 22180

NOVEMBER 1980
FINAL REPORT

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research & Development Service
Washington, D.C. 20590

NOTICE

Technical Report Documentation Page

1. Report No. 18 19 FAA-RD/80-128	2. Government Accession No. AD A043 293	3. Recipient's Catalog No. 11
4. Title and Subtitle 6 National Airspace Data Interchange Network (NADIN) COMMUNICATIONS SUPPORT FOR FLIGHT SERVICE AUTOMATION SYSTEM		5. Report Date NOV[redacted]80
		6. Performing Organization Code
7. Author(s)		8. Performing Organization Report No. 14 NAC/FR-303A/01
9. Performing Organization Name and Address Network Analysis Corporation 301 Tower Building Vienna, VA 22180		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. 15 DOT-FA79WA-4355
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration System Research and Development Service Washington, DC 20590		13. Type of Report and Period Covered 9 Final Report, 1979-1980.
		14. Sponsoring Agency Code FAA/ARD-200

15. Supplementary Notes

12 217

16. Abstract

The FSAS service was analyzed to determine NADIN enhancements required to support FSAS data communications. The analysis yielded the following conclusions:

- The NADIN backbone architecture fits FSAS needs and requires no change; however, the NADIN switch to concentrator line speeds need to be increased from 4.8 to 9.6 Kbits/second.
- The FSAS file transfers may cause relatively long delays to Service B and AFTN messages. By having the switches systematically intersperse frames of messages going to different concentrator input circuits, the delay effects of these file transfers can be minimized.
- Control of AWP message transmissions is recommended. Flow control will result in a more efficient use of the processing and memory resources of NADIN switches.
- The AWP and FSDPS software should be designed to enable the AWPs to interrupt large weather file transmissions to send shorter messages.

17. Key Words		18. Distribution Statement
Data Communications	NADIN	Document is available to the U.S. Public through the National Technical Information Service, Springfield, VA 22161
Traffic Requirements	FSAS	
File Transfers	AWP	
Switch Output Procedure	FSDPS	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	21[illegible]	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

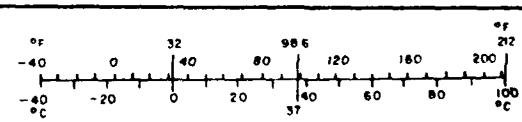

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

PREFACE

The National Airspace Data Interchange Network (NADIN) is being developed, in its initial phase, as a common data communications network that will integrate various FAA communications services, specifically those involved in the exchange of information pertaining to air traffic. Current FAA plans call for the implementation of NADIN in the early 1980s. The initial design is specifically directed to the absorption of the Aeronautical Fixed Telecommunication Network (AFTN), NASNET, the most of Service B. The design also provides for the expansion of NADIN facilities and circuits so as to accommodate growth, both in terms of requirements for included services and in terms of additional services.

Concurrently with efforts to implement the initial NADIN design, efforts are being directed to the analysis of other services that might be integrated into NADIN. The integration of FSAS communication requirements into the NADIN system will require a variety of information:

- guidance for the NADIN program team to determine NADIN enhancements and specification amendments necessary to support FSAS data communications;

- a technical data package supporting the writing of interface specifications by NADIN and FSAS R&D teams;

- a performance data package containing pre-implementation estimates of response times in NADIN after the integration of FSAS traffic;

- an analytical model to assess post-FSAS performance of NADIN.

Rapid reference to each of the above issues is achieved by making the sections of each chapter self contained and by including the information which is too detailed or too technical in appendices. Table I is a guide to the report and gives the suggested reading for each of the issues mentioned above.

Special Areas of Interest	Sections					Appendices
	Ch. 1	Ch. 2	Ch. 3	Ch. 4	Ch. 5	
NADIN enhancements	1-3, 7	2	3	-	All	H
Cost of enhancements	1-3, 7	4	6	2,5	1,2	Q,R,S
FSAS-NADIN interface	1-2,4,7	1,3	5	4	1,3	J
NADIN performance	1,2,3,7	1,2	-	3	1	-
Analytical queueing models	-	-	1-4	1-4	-	I to P

TABLE 1: SUGGESTED SELECTIVE READINGS OF REPORT

CHAPTER 1

INTRODUCTION

1.1 SUMMARY OF FINDINGS

Although the initial NADIN will require some enhancements, it can be expected to accommodate FSAS requirements with minimal cost and performance penalties. The integration of FSAS data communications into NADIN constitutes a substantial cost saving in comparison with a network of lines dedicated to FSAS.

1.2 FSAS IMPACT ON NADIN PERFORMANCE

The delays of messages in NADIN will increase after the introduction of FSAS traffic but will still be within the limits set in the NADIN specification. The NADIN switches will require larger buffer spaces to accommodate FSAS files waiting for transmission. The amount of buffer will depend on whether or not a NADIN switch can temporarily inhibit transmission from the attached Aviation Weather Processor (AWP). The processing load on the NADIN switches and concentrators is likely to still be acceptable after the introduction of FSAS traffic due to the low initial utilization of NADIN.

1.3 NECESSARY NADIN ENHANCEMENTS

The introduction of FSAS traffic can be handled with line speed increases; it can best be accommodated by an appropriate design of NADIN switches. Controlling the flow of messages between the AWPs and the NADIN switches provides additional advantages.

NAC recommends increasing the data transmission rate of NADIN trunk lines between switches and concentrators from 4.8 to 9.6 Kbits/second. This increase will guarantee that message network delays are on the average less than the two seconds set by the NADIN specification. However, the two seconds delay will be exceeded for a few minutes each hour when large FSAS files are transmitted, unless the NADIN switch output discipline is modified.

An appropriate design of NADIN switches will give equal to treatment to all users and prevent the monopolization of a switch to concentrator line for several seconds by a long

FSAS file message. These modifications of the NADIN switch design can be accomplished during the pre-implementation period and need not be a modification to an existing system.

Controling the flow of messages between AWPs and NADIN switches will prevent an unnecessary backlog of untransmitted FSAS file weather frames at the switches. The software necessary to implement such a flow control is an extension of the FSAS software which formats data into NADIN messages.

An alternative to modifying the switch design and flow control between FSAS and NADIN is a line speed of 19.2 Kbits/second between NADIN switches and concentrators. This speed ensures that FSAS file messages are flushed from the NADIN switch fast enough to not overly delay other NADIN traffic. By ensuring a rapid transmission of FSAS weather files from the AWPs to the Flight Service Data Processing Systems (FSDPS), this line speed of 19.2 Kbits/second also prevents an accumulation of a large backlog of frames at the switch and the strain on switch primary storage resources.

A modified switch design and NADIN-FSAS flow control is technically and economically efficient. It also provides a rational basis for future extensions of NADIN's services. The alternative of line speeds of 19.2 Kbits/second or beyond is viable but less cost-effective.

1.4 COST OF ENHANCEMENTS

The cost of NADIN enhancements varies from small for the implementation of an option that uses FSAS/NADIN flow control and an appropriate switch discipline, to sizeable for an option that relies on the use of high speed lines between NADIN switches and concentrators. In all cases, the cost of NADIN enhancements is dwarfed by the cost of a dedicated lines contingency solution for FSAS communication needs.

1.5 FSAS/NADIN INTERFACE

The FSAS and NADIN nodes are compatible at all levels of physical, link and message interfaces. A further characterization of the interface at the message level should be addressed jointly by the NADIN and FSAS program teams. The issues to be jointly discussed include:

- FSAS-NADIN flow control alternatives,

- priorities of FSAS messages,
- choice of NADIN message headings to be entered in FSAS messages,
- mutual responsibilities of FSAS and NADIN programs in entering message headings.

The outcome of the joint decisions by NADIN and FAA teams can be in the form of an interface document included in both the FSAS and NADIN specifications.

1.6 BASIS OF NADIN ANALYSIS

The recommendation that FSAS use an enhanced NADIN is based on performance constraints, interface requirements, cost considerations and the following key assumptions: (1) FSAS traffic and operation in accordance with the FSAS specification, (2) NADIN operation in accordance with the NADIN specification, (3) traffic restricted to FSAS, Service B and AFTN traffic and (4) treatment of initial NADIN costs as a sunk investment.

The FSAS traffic to be supported by NADIN consists of the data exchanges between AWPs, FSDPSs, and external systems. The local traffic between FSDPSs and Automated Flight Service Stations (AFSS) will be on dedicated lines at the start of the automation program, although NADIN may be considered in the future. The alphanumeric weather data from the National Weather Service (NWS) will be transmitted to the AWPs through the Weather Message Switching Center (WMSC). The WMSC is assumed to remain in place for the foreseeable future.

A mathematical model of NADIN that represents a queueing procedure by the switches and concentrators that is consistent with the design constraints given in the NADIN specification has been formulated. The queueing procedure modeled is one of possibly several approaches contractors may use to satisfy the NADIN requirements. The model provides a rational basis on which to examine the impact of FSAS traffic. The results are expected to be similar in any approach that is consistent with the specification. A different queueing procedure which gives more "equitable" treatment to all NADIN users is also described and shown to solve the delay problems caused by large FSAS file transfers that are transmitted at high speeds.

The traffic loading of NADIN considered in this study consists of the FSAS and the initial Service B and Aeronautical Fixed Telecommunication Network (AFTN) traffic. The

later integration of Flight Data Entry Printout (FDEP) and Automated Flow Control (AFC) systems into NADIN may require further NADIN enhancements. While this question is not quantitatively addressed in this study, the reserve capacity in a 9.6 Kbit/second line between switches and concentrators may be sufficient to carry FDEP and AFC traffic and still satisfy NADIN delay requirements.

The FSAS traffic data is an updated version of the traffic requirements in the FSAS hardware specification (Reference 2). This update accounts for the future expansion of the FSAS. The NADIN traffic data is taken unchanged from the NADIN specification (Reference 1). The traffic requirements of Service B and AFTN may have increased since the writing of the specification. However, since this initial NADIN traffic results in a utilization of 10% or less, the conclusions and recommendations made here would not change even with a doubling of original traffic throughput.

1.7 METHODOLOGY

The methodology applied here consists of the sequential completion of a requirements analysis, alternatives generation and analysis, and comparative analysis. Analytic queueing models are used for performance analysis while discounted present value analysis is used for cost comparison analysis.

The FSAS traffic requirements consist of the traffic statistics: message lengths and message arrivals. The requirements consider maximum traffic on generic NADIN backbone links: switch to switch, switch to concentrator and concentrator to switch. The switch to switch link is loaded with processed files exchanged between the AWPs. As a worse case assumption, this AWP to AWP traffic is considered equal to the AWP to FSDPS traffic.

Overhead is added to the raw traffic data so as to adequately represent the total impact on the NADIN system. The link and message protocol overheads are added to the length of messages, the number of messages per unit time is increased to account for control messages, and NADIN messages are broken into smaller ADCCP frames.

The generation of alternatives results from an analysis and interpretation of the NADIN specification. One interpretation of the queueing procedure at the NADIN switches resulted in large delays for non-FSAS messages. To remediate this problem, a number of alternatives are considered. Another queueing procedure giving more equitable treatment to non-FSAS messages and smaller resultant delays is analyzed. Trunk line speeds of 4.8, 9.6 and 19.2 Kbits/seconds between switches and concentrators are considered. In the case of

4.8 and 9.6 Kbits/seconds lines, it is asssumed that the switch output queueing procedure is a modified version of the procedure indicated by the NADIN specification. The line speed of 19.2 Kbits/second is a "brute force" method of quickly emptying the switch buffer of temporarily accumulated FSAS files. If the switch memory resources are sufficient, a 19.2 Kbit/second line speed may not be necessary.

The non-NADIN alternative is an FSAS contingency plan of dedicated lines between AWPs, FSDPSs and the WMSC. The contingency plan is evaluated here only for cost comparison with NADIN alternatives.

The results of the analysis of NADIN's performance are the delays of messages through NADIN and the buffer space needed at switches and concentrators to accommodate waiting messages. The several alternatives for NADIN's operation and traffic loading create the need for separate analyses. There are separate models for two queueing procedures at the switches and separate models for times of FSAS file transfers and times between file transfers. An analysis is also made of the queue build up at the NADIN switches in the absence of a control of message flow from the AWP. The separate analyses of NADIN at times of FSAS file transfers and between file transfers are needed because calculations based on average hourly traffic do not give an accurate picture of NADIN's operation. Instead, traffic data is grouped into scheduled and unscheduled messages. Of the scheduled messages, *Surface Observations and Winds Aloft* files are singled out for analysis because of their length and closeness of transmission times. The duration of a busy period is calculated to estimate the periods during which message delays are large. (A "busy period" is the time between the arrival of the first frame of a file at the switch and the departure of the last frame from the switch). The various NADIN models are also used repeatedly to determine the effect of line speeds and message overhead on delays and buffer requirements. Assumed sizes of NADIN headers are: 1) 20 characters, a minimum and 2) 63 characters, a likely figure unless both the FSAS and NADIN programs make a deliberate effort to reduce overhead.

Most of the *analytical queueing tools* used to determine average and 90$^{\underline{th}}$ percentile times are specially developed for this task. The model and results that arise in a standard M/G/1 queue are also used in several instances (Reference 21).

The cost comparison analysis is a present value comparison, referring NADIN sub-alternatives and contingency plan costs to present day for a three year utilization. The costs considered for NADIN sub-alternatives are the costs of higher speed modems and extra voice grade lines (when needed), extra ports and cost of software to interface with FSAS.

Only incremental costs are considered since the initial NADIN investment is considered a sunk cost. The pricing of the contingency plan includes the cost of leased lines, modems and WMSC and AWP interfaces.

1.8 CHARTER

This report is Deliverable C4 of Task 1 of Contract DOT-FA79WA-4355 which requests the technical and cost basis for FSAS integration into NADIN. This report integrates the results of previous contractual Deliverables C1, C2 and C3 as well as NAC's study on FSAS-NADIN interface (NAC WM.303A.04). It will be appropriately revised into a final report that accommodates FAA review comments.

CHAPTER 2

RESULTS OF NADIN PERFORMANCE ANALYSIS

The delays of messages in NADIN and the buffer requirements at the NADIN switches are acceptable provided line speeds between switches and concentrators are increased to 9.6 Kbits/second and are even better with an appropriately modified design of switch operation and interface.

An appropriate switch design provides small delays for non-FSAS messages even at the times of FSAS file transfers. A flow control procedure between AWPs and NADIN switches has the merit of preventing files from arriving at the switches faster than they can be retransmitted, thus minimizing memory hardware requirements at the switches. Flow control is also a feature which will give flexible (e.g., priority sensitive) control to the future NADIN over its many users. However, the implementation of flow control between FSAS and NADIN is not a necessity at this time since NADIN switches will have enough buffer space to accommodate file backlogs. However, flow control should be given consideration by the NADIN and FSAS programs because of its long term desirability.

The increase of line speeds to 19.2 Kbits/second is a brute force method of forcing down the delays of messages at times of file transfers and the memory requirements at the switches.

This chapter summarizes the results of FSAS traffic requirements analysis, NADIN performance, and cost comparison analysis. The analysis and detailed results are in Chapter 4. Section 2.1 describes FSAS traffic. Section 2.2 gives the delays of NADIN messages and the buffer requirements at switches and concentrators for: (1) modified switch operation and FSAS-NADIN flow control, (2) unmodified switch operation and, (3) no FSAS-NADIN flow control. Section 2.3 presents the results of the FSAS-NADIN interface analysis and Section 2.4 addresses the cost comparison of FSAS communication alternatives.

2.1 FSAS TRAFFIC CHARACTERIZATION

Analysis of FSAS requirements has shown FSAS traffic to be a factor of four larger than initial Service B and AFTN traffic and to consist in part of large file transfers. FSAS is thus NADIN's largest user and requires proper management of switch resources to prevent undue delay of non-FSAS messages.

The main components of FSAS traffic are alphanumeric and graphic weather data transiting from AWPs to FSDPSs. This weather information also transits between the AWPs which dynamically share the processing load and send each other processed weather data. Other FSAS traffic consists of weather reports from FSDPSs to AWPs, flight plans exchanged between FDSPSs and ARTCCs and air flow control messages. The traffic between FSAS and external systems like the WMSC and NMC is not considered unless it is transmitted on a NADIN backbone link (e.g., FSDPS to WMSC).

AWP Traffic: The AWPs maintain a national weather data base at all times. The raw weather products received from the FSDPSs, from Service A in the WMSC, and from the NMC are processed by an AWP which then transmits the processed data to its attached FSDPSs and to the other AWP. An AWP also transmits the unprocessed weather data to its attached FSDPSs.

The AWP to FSDPS and AWP to AWP traffic consists of unscheduled messages processed as they come and large files arriving at pre-scheduled times. These two types of traffic are handled separately in the analysis. Figure 2.1 shows the peak hour traffic throughput of scheduled and unscheduled messages (See Appendix C for details). Figure 2.2 shows the duration of busy periods created by Surface Observation and Winds Aloft files with trunk line speeds of 4.8 and 9.6 Kbits/second. Figure 2.3 shows the duration of busy periods throughout the day for a 9.6 Kbits/second trunk speed.*

FSDPS Traffic: The FSDPSs transmit Surface Observations, Pilot Reports and Notams to the AWPs and to the WMSC. The FSDPSs also transmit Flight Plans to other FSDPSs and ARTCCs. The traffic between FSDPSs and AFSSs is documented in Appendix E.

In addition to traffic figures, FSAS node locations and numbers are given in Appendix B.

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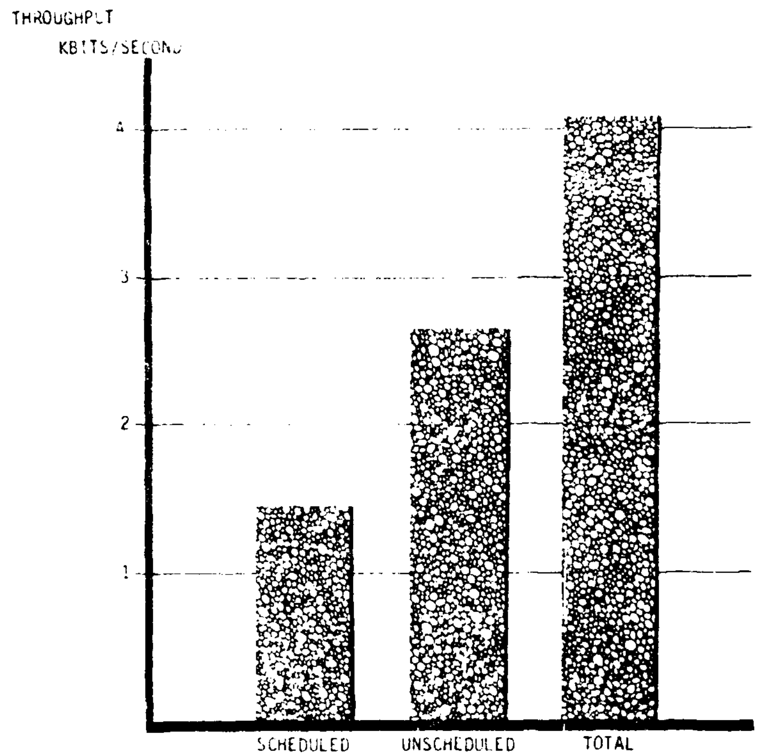
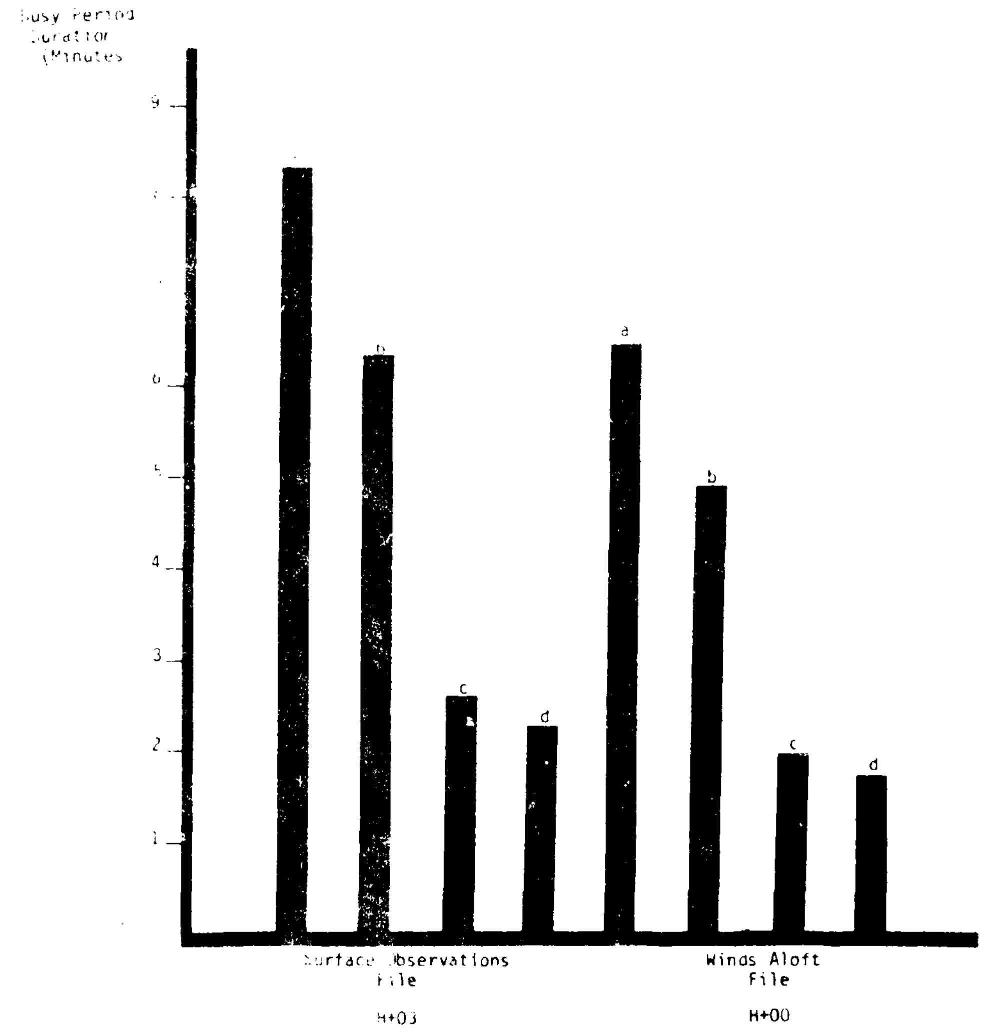
* The times of transmission of files shown in Figure 2.2 accurately represent the best available information at the time of report preparation. Reviewer comments indicate that busy periods may be more evenly distributed throughout the day. These discrepancies may be due to the lack of information when preparing this report or subsequent schedule changes. Any such changes will mean that these results are conservative.



PEAK HOUR AWP TO FSDPS TRAFFIC THROUGHPUT
(63 Overhead Characters per NADIN message)

FIGURE 2.1



a: Switch to concentrator:4.8 Kbps, NADIN overhead: 63 characters
b: Switch to concentrator:4.8 Kbps, NADIN overhead: 20 characters
c: Switch to concentrator:9.6 Kbps, NADIN overhead 63 characters
d: Switch to concentrator:9.6 Kbps, NADIN overhead 20 characters

FIGURE 2.2: DURATION OF BUSY PERIODS

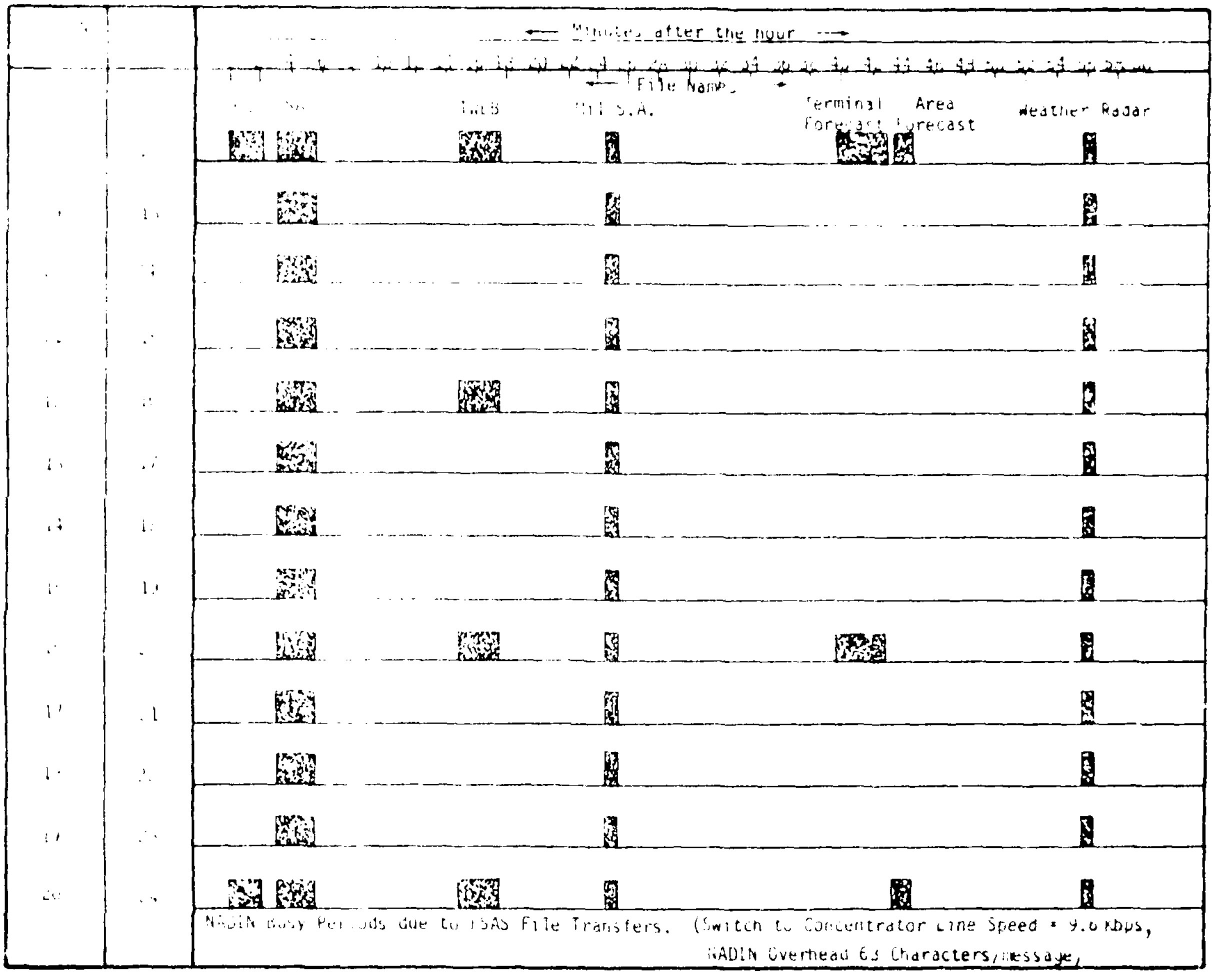


FIGURE 2.3: DURATION OF BUSY PERIODS THROUGHOUT THE DAY

2.2 DELAYS AND BUFFER REQUIREMENTS

The analysis of NADIN performance and the delay requirements of the NADIN specification indicates the following line speeds between switches and concentrators should be used:

Appropriately Modified Design of Switch Queueing: A line speed of 9.6 Kbit/second is recommended. If the switch gives equitable treatment to all concentrator output ports, a line speed of 4.8 Kbits/second will only be marginally sufficient in satisfying the NADIN specification requirements.

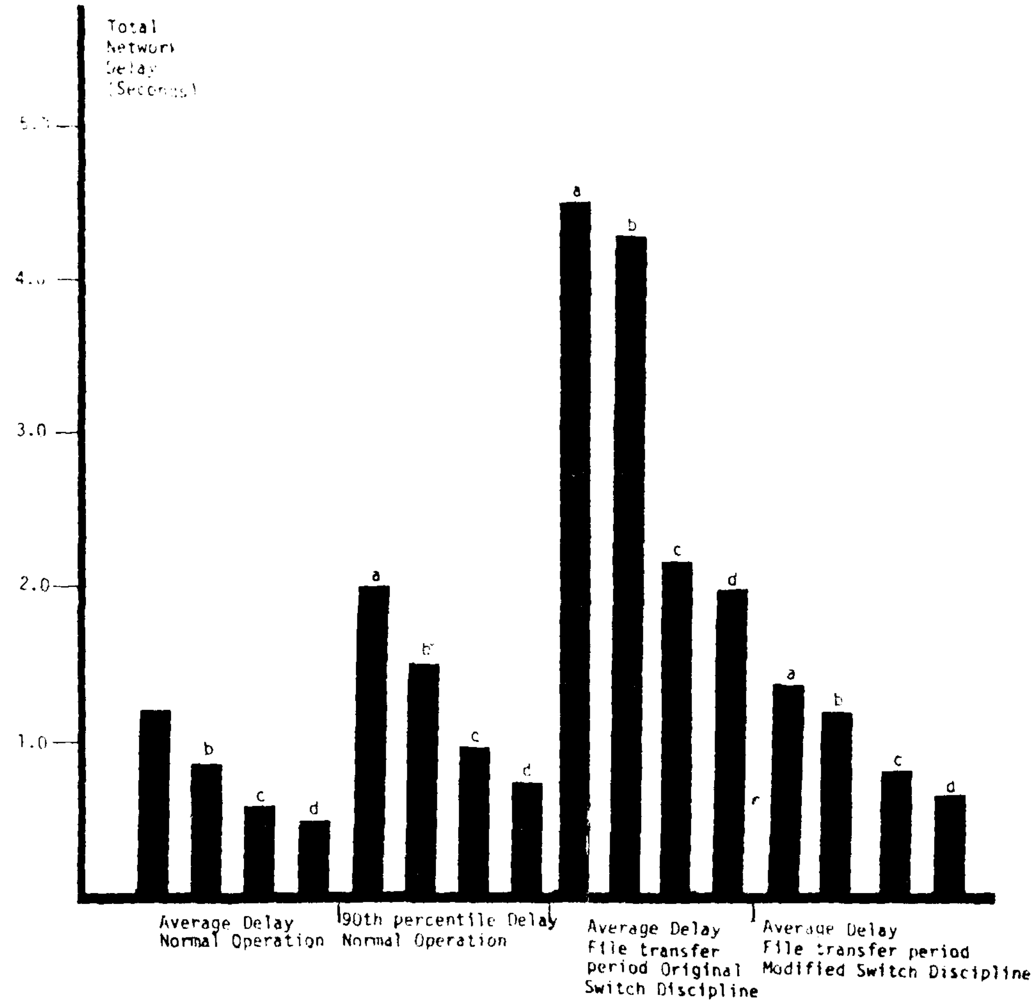
A 9.6 Kbits/second line speed will lower the delays of FSAS unscheduled messages at times of file transfers from 5 to 2.5 seconds (approximately) and reduce the size of buffer required at the switches in the absence of NADIN-FSAS flow control from about 170 Kbytes to 25 Kbytes (given that the interface is limited to 9.6 Kbits/second). This better performance justifies the use of 9.6 Kbits/second lines.

Original Switch Design: A line speed of 19.2 Kbits/sec is necessary to bring the initial NADIN message delays below 2 seconds (the value set by the NADIN specification) at times of file transfers.

2.2.1 Delays and Buffer Requirements with Appropriate Design of Switch Operation and Interface

Both the average delay of all initial NADIN messages (Service B and AFTN) and the buffer requirements at the switches are acceptable with no increases in line speeds provided: (1) the switch to concentrator line is not monopolized by messages going to high speed concentrator output ports and (2) the switch can pace the AWP transmission of large file messages. However, the delays of FSAS unscheduled messages are about six seconds during busy periods. In addition, since 4.8 Kbits/second trunk lines would have a very high utilization, 9.6 Kbits/second lines are recommended.

Figure 2.4 shows the delays of Flight Plans and initial NADIN Service B and AFTN messages going through a complete concentrator-switch-switch-concentrator path in NADIN. At all times, these delays are approximately half the 2 seconds imposed by the NADIN specification, provided the switch service discipline is modified to give equitable treatment to all messages.



a: Switch to concentrator:4.8 Kbps, NADIN overhead: 63 characters
b: Switch to concentrator:4.8 Kbps, NADIN overhead: 20 characters
c: Switch to concentrator:9.6 Kbps, NADIN overhead: 63 characters
d: Switch to concentrator:9.6 Kbps, NADIN overhead: 20 characters

FIGURE 2.4: DELAYS OF INITIAL NADIN MESSAGES

Figures 2.5 and 2.6 show the delays for two types of FSAS messages: Flight Plans from an FSDPS to another FSDPS and unscheduled weather messages from an AWP to an FSDPS. The delays are one second or less at normal times but rise to about 2.5 and 5 seconds at times of file transfers if switch to concentrator speeds are 9.6 and 4.8 Kbits/sec, respectively.

The buffer sizes needed at switches and concentrators are shown in Figures 2.7. The values in Figure 2.7 indicate buffer sizes needed at all times if flow control between AWPs and NADIN switches is implemented. The scheduled FSAS traffic, not accounted for in the calculations leading to Figure 2.7, will make the actual buffer occupancies higher.

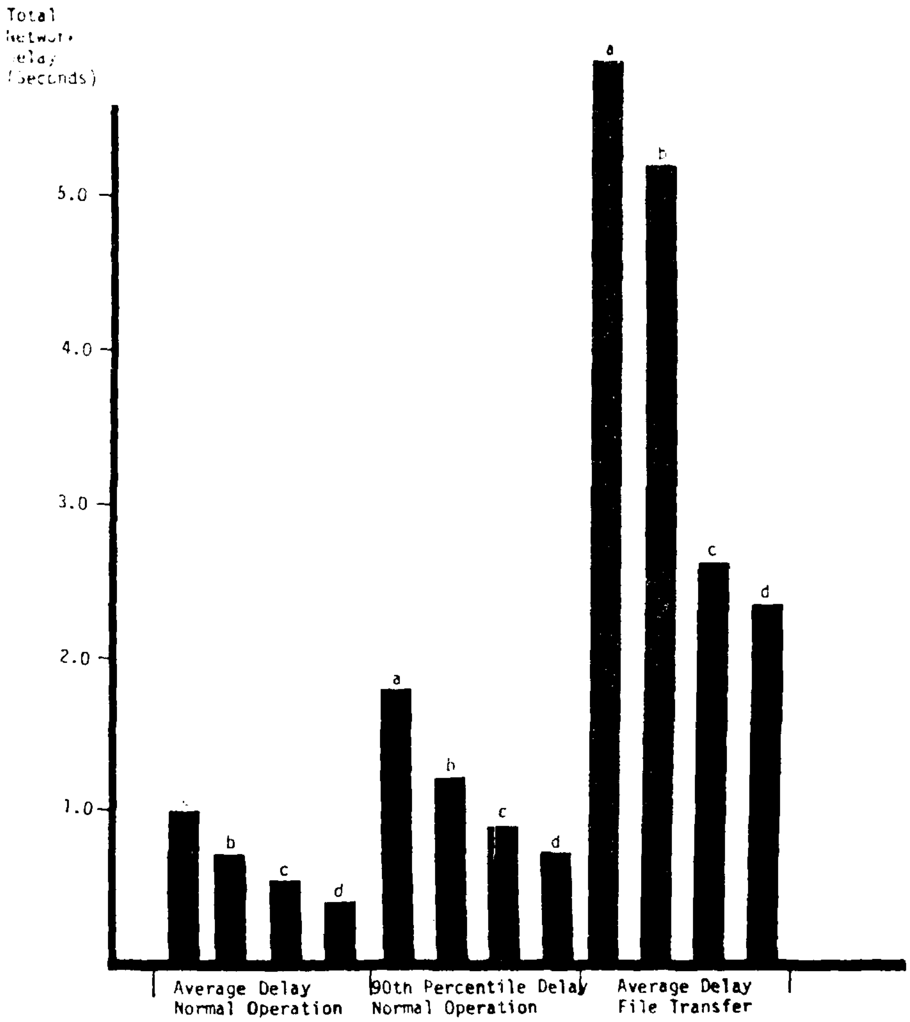
The results of NADIN modeling show that with an appropriate switch queueing procedure and with data flow control between AWP's and switches, the existing line speed of 4.8 Kbits/second between switches and concentrators only marginally satisfies NADIN delay requirements. The FSAS unscheduled traffic will suffer some degradation at times of file transfers, with delays of the order of 5 seconds. A line speed of 9.6 Kbits/sec between switches and concentrators brings this delay down to about 2 seconds and further improves the response time of other non-FSAS messages.

2.2.2 Delays in the Presence of Unmodified Switch Operation

In the absence of "fair" treatment of all NADIN users, line speeds of 19.2 Kbits/second between switches and concentrators are necessary to bring down delays of all messages to the levels required in the NADIN specification. The delay of a NADIN message is caused by FSAS file messages which monopolize the switch to concentrator lines for the duration of their transmission (approximately 7 seconds on a 4.8 Kbits/second line). Figures 2.4, 2.5 and 2.6 show the delays of initial NADIN and FSAS messages at the times of file transfers with an unmodified switch operation. The delays are brought down to about 2 seconds with a 9.6 Kbits/sec line between switch and concentrator. Delays are thus roughly equal to delay times set by the NADIN specification. A safe engineering design value for the line speeds must be higher than 9.6 Kbits/sec. The next speed of 19.2 Kbits/sec (using two voice grade lines) must therefore be used.

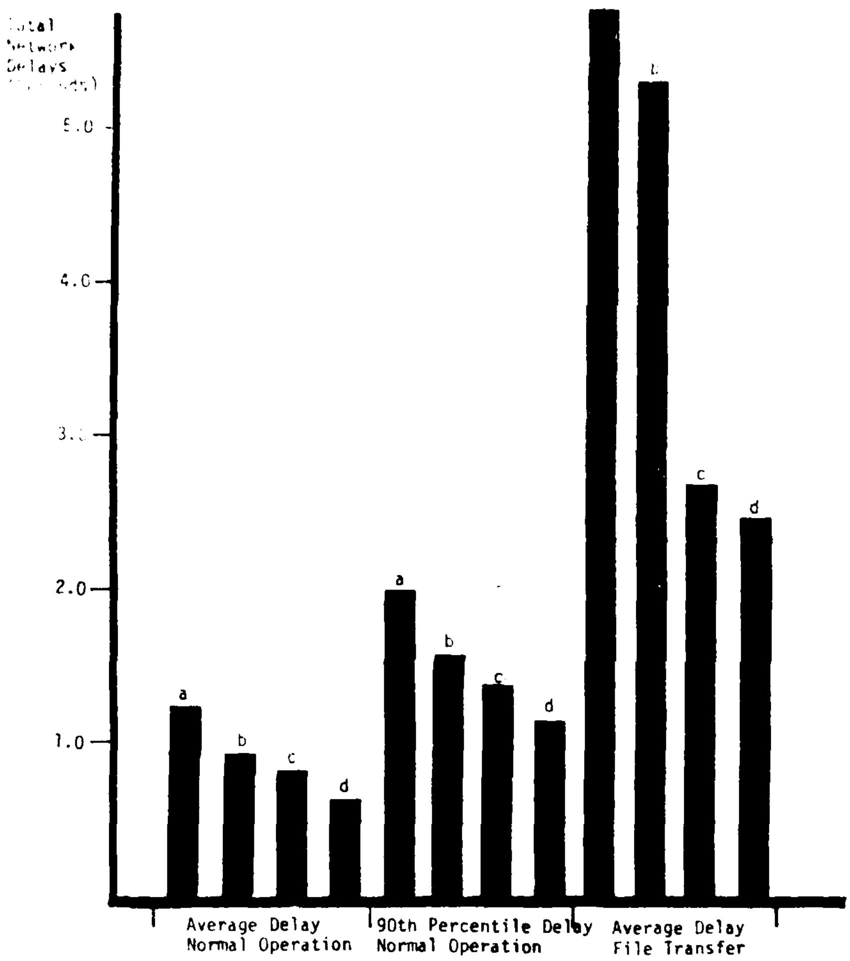
2.2.3 Buffer Requirements in the Absence of AWP/NADIN Switch Flow Control

In the absence of flow control and with a 9.6 Kbits/second trunk speed, the buffer space required at the NADIN switches to accommodate waiting frames at times of file



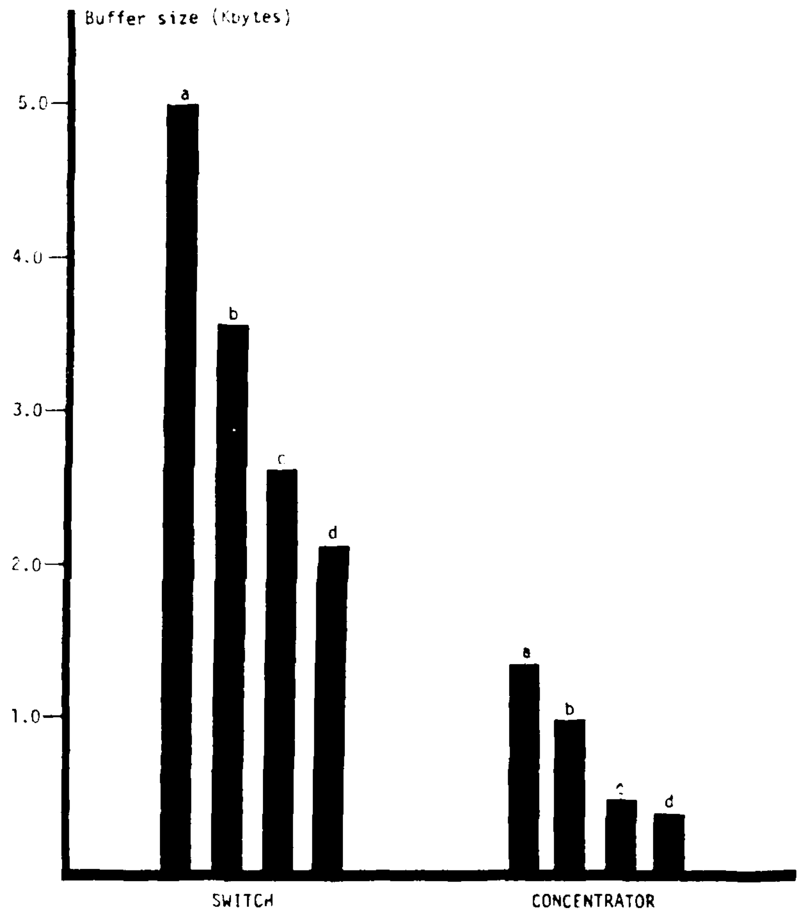
a: Switch to concentrator:4.8 Kbps, NADIN overhead: 63 characters
b: Switch to concentrator:4.8 Kbps, NADIN overhead 20 characters
c: Switch to concentrator:9.6 Kbps, NADIN overhead: 63 characters
d: Switch to concentrator:9.6 Kbps, NADIN overhead: 20 characters

FIGURE 2.5: DELAYS OF FLIGHT PLANS FROM FSDPS TO FSDPS



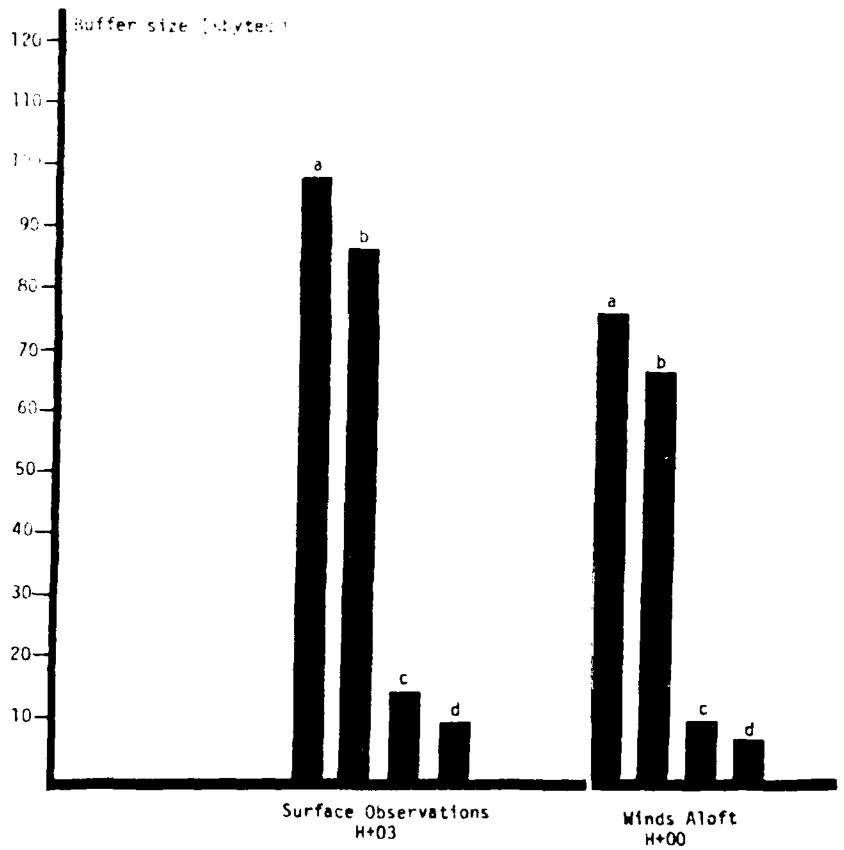
a: Switch to concentrator:4.8 Kbps, NADIN overhead: 63 characters
b: Switch to concentrator:4.8 Kbps, NADIN overhead: 20 characters
c: Switch to concentrator:9.6 Kbps, NADIN overhead: 63 characters
d: Switch to concentrator:9.6 Kbps, NADIN overhead: 20 characters

FIGURE 2.6: DELAYS OF UNSCHEDULED MESSAGES, AWP TO FSDPS



a: Switch to concentrator:4.8 Kbps, NADIN overhead: 63 characters
b: Switch to concentrator:4.8 Kbps, NADIN overhead: 20 characters
c: Switch to concentrator:9.6 Kbps, NADIN overhead: 63 characters
d: Switch to concentrator:9.6 Kbps, NADIN overhead: 20 characters

FIGURE 2.7: BUFFER SIZE OF NADIN NODES FOR 5 OVERFLOW PROBABILITY: TIMES BETWEEN FILE TRANSFERS



a: Switch to concentrator:4.8 Kbps, NADIN overhead: 63 characters
b: Switch to concentrator:4.8 Kbps, NADIN overhead: 20 characters
c: Switch to concentrator:9.6 Kbps, NADIN overhead: 63 characters
d: Switch to concentrator:9.6 Kbps, NADIN overhead: 20 characters

FIGURE 2.8: BUFFER OCCUPANCY AT SWITCHES: NO FLOW CONTROL

CONTROL BETWEEN AWP AND SWITCH

transfers is of the order of 20 Kbytes (assuming the AWP/NADIN interface operates synchronously and at a speed of 9.6 Kbits/second). The memory capacity of NADIN switches will be enough to handle that load. If desired, a further reduction may be achieved by line speeds of 19.2 Kbits/second.

Figure 2.8 shows the amount of buffer space needed at the switches at the times of Surface Observations and Winds Aloft transfers. In the case of 4.8 Kbits/second trunk lines, Surface Observations will come before Winds Aloft are transmitted, and there will be frames of both files waiting at the switch.

2.3 COMPATIBILITY OF FSAS AND NADIN NODES

The FSAS and NADIN nodes are compatible at all levels of physical, link and message interfaces. A further characterization of interface at the message level should be addressed jointly by the NADIN and FSAS program teams. They should decide which NADIN headers are present in the FSAS message and the division of responsibilities for inclusion of headers. The question of flow control between AWPs and NADIN must also be addressed. Table 2.1 gives the structure of the NADIN message header and some recommendations on its use for FSAS messages. Table 2.2 gives a suggested assignment of NADIN priorities to FSAS messages.

2.4 DISCOUNTED PRESENT VALUE COMPARISON OF FSAS COMMUNICATION ALTERNATIVES

The various NADIN alternatives are all more cost effective than a non-NADIN alternative for FSAS communications requirements. The present value cost of the following FSAS communications alternatives are shown on Figure 2.9:

- NADIN Scenario 1 - flow control and 4800 b/s trunking (minimum adequate)
- NADIN Scenario 2 - flow control and 9600 b/s trunking (reserve capacity)
- NADIN Scenario 3 - no flow control and 19200 b/s trunking (brute force)
- Leased line alternative - a communication contingency plan consisting of point-to-point 9600 b/s and multidrop 2400 b/s lines.

Name of Header	Length Min	Max	Assumed	Comment	To be Used by FSAS	Choice of characters to be entered
Message Heading						
Start of heading	2	2	2	Same for all messages	Y	N
Supervisory information	2	69	7	Transmission identification. Not mandatory when recovery is not required.	N.D.	F,N
Priority	2	2	2	One of seven priorities	Y	F,N
Addresses	4m	9m	9	One message can go to m locations	Y	F,N
Date Time group	6	6	6	Day, hour and minute message was prepared.	Y	F
Message originator	4	9	9	Address of originator	Y	N
Length Subtotal	20		35			
Subfield A of Optional Data Field						
Message type	3	8		e.g. Graphics, Baudot	Y	F,N
Privacy	2	2		Type of privacy	N.D.	F,N
Acknowledgement	1	1		Defines type of system acknowledgement	N.D.	F,N
Billing	1	1		Class of billing	N.D.	N
Text code and format	2	2		For non ASCII texts	N.D.	F,N
Text length	4	4		*Mandatory for graphics*	Y	F
Subfield B of Optional Data Field						
Authentication key	6	8		For privacy	N.D.	F,N
Possible duplicate message	3	3		Used in case accountability is needed during recovery	N.D.	F,N
File number	?	?		ADP file number	N.D.	F,N
Data Sequence Number	2	2		For messages exceeding 3700 characters.	Y	F
Subfield C of Optional Data Field						
Additional information now undefined.						
Total length for A,B,C			27			
Message Text	0	3700				
Message ending	1	1	1	ASCII ETX	Y	N
Total overhead	45	129	63			

Key: Y = Yes
N.D. = Not Decided
F = FSAS responsibility
N = NADIN responsibility
F,N = joint FSAS and NADIN responsibility

Table 2.1: STRUCTURE OF NADIN MESSAGE

NADIN Priority 2:	Flight related messages such as flight plans and flow control messages from the ATCSCC.
NADIN Priority 3:	Weather related messages which are transmitted on an individual basis such as Pilot Reports, Surface Observations from automated flight service stations and AFOS graphics.
NADIN Priority 4:	Large files of weather data coming from the WMSC and retransmitted by the AWP after processing. For example Winds Aloft and Surface Observations.

TABLE 2.2: PRIORITIES RECOMMENDED FOR FSAS MESSAGES

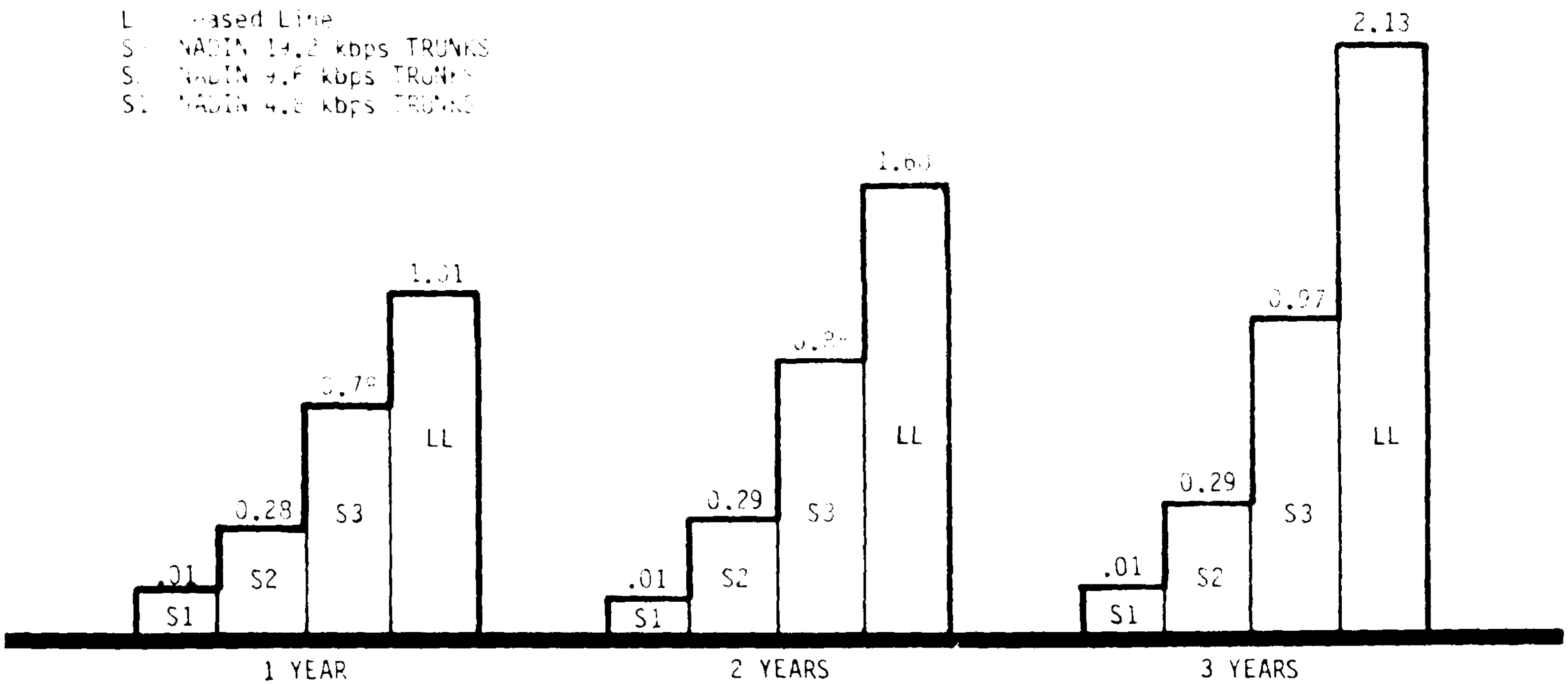


FIGURE 2.9 PRESENT WORTH (MILLIONS OF DOLLARS) OF ALTERNATIVES VS. COMPARISON PERIOD

CHAPTER 3

BASIS OF NADIN FSAS STUDY

This study is based on information collected from the applicable FAA documents on FSAS and NADIN, in particular the functional specifications (References 1 to 4). This chapter documents in some detail the available data about FSAS and NADIN, their traffic requirements, the communications alternatives considered, as well as the analytical models used for performance and cost evaluation.

3.1 BASIS OF SYSTEM CONFIGURATION AND OPERATION OF NADIN, INITIAL NADIN TRAFFIC

The physical configuration of NADIN and the line speeds of its backbone network are explicitly given in the NADIN specification (see Figure 3.1). The operation of the NADIN switches and concentrators is inferred from the functional requirements in the NADIN specification. The same document also defines the NADIN interface protocols and the expected data traffic at the inception of NADIN. These issues are examined in some detail below since they form the basis of the analytical models in the next chapter. In particular, message output queueing discipline at NADIN nodes is described in detail because the discipline affects message delays. An interpretation of a switch operation (not necessarily unique) which accommodates all the performance constraints imposed by the NADIN specification is given below. Section 3.4 describes an alternative switch operation giving more equitable treatment to non-FSAS messages. More equitable treatment is essential if integration is to be accomplished without requiring an excessive overbuild of transmission capacity.

The description of NADIN given here provides the basis for the mathematical modeling of message delays in the next chapter. The components of delay time are the waiting and processing times at switches and concentrators (nodal delays) and the waiting and transmission times on the NADIN backbone lines (line delays). The emphasis here is placed on line delays rather than nodal delays. The analysis of nodal delays must be based on the internal modeling of switches and concentrators and in turn requires knowledge of the specifics of the NADIN implementation. This information is not yet available. As a result,

nodal delays cannot be predicted with accuracy. However, these delays are typically smaller than line delays and may be ignored without significantly affecting the overall results.

3.1.1 NADIN Physical Configurations and Line Speeds

The NADIN architecture is compatible with the FSAS. The AWP and FSDPS are colocated with the switches and concentrators, respectively. NADIN is a network comprised of two switching centers (Atlanta and Salt Lake City) which are connected to a total of 23 regional concentrators (Figure 3.1). Trunk lines interconnect the switches and connect each switch to 11 or 12 concentrators. Since most of the FSAS traffic is between AWP and FSDPS or between AWP's, i.e., between switches and concentrators, it is unnecessary to consider changes to the NADIN architecture to accommodate FSAS traffic.

The routing in NADIN is centralized, in the sense that any message has to pass through a switch before reaching its destination. NADIN's routing, like its architecture, fits the FSAS traffic, which in general either originates at, or is destined to, the AWP's at Atlanta and Salt Lake City. One notable exception are the IFR flight plans going from an FSDPS to the colocated NAS 9020 computer. These must travel all the way to the switch and back before reaching their destination. However, the amount of such traffic is quite small in comparison to the rest of FSAS traffic and will not significantly affect delays. Accordingly, for the purpose of analysis, it is assumed that concentrators do not have a local switching capability. If they do have this capability at the time of implementation the expected values of delays obtained here will be on the conservative side, but still realistic.

In conclusion, the NADIN architecture and routing are considered fixed and need not be altered to accommodate FSAS traffic.

The line speeds of links in the initial NADIN are shown in Figure 3.1. Two Full Duplex (FD) lines with 9.6 Kbps modems connect the switches and FD lines with 4.8 Kbps modem connect switches and concentrators. Alternative line speeds of 9.6 and 19.2 Kbps between switches and concentrators are also considered in the analysis (See Section 3.3).

3.1.2 NADIN Switches and Concentrators

The switches and concentrators perform various functions on the messages they receive, to ensure proper routing as well as to satisfy the user requirements for journalling,

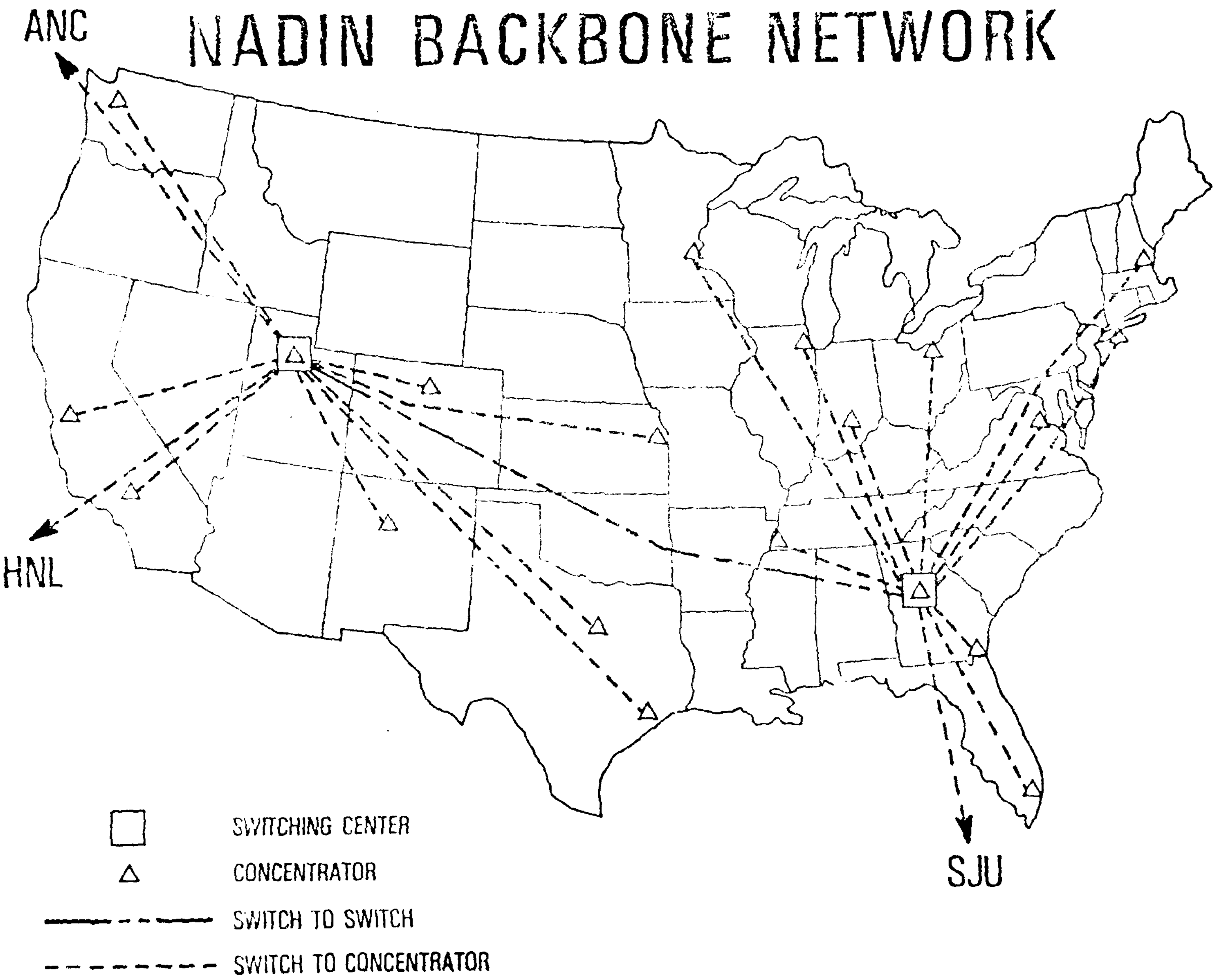


FIGURE 3.1: NADIN BACKBONE NETWORK

[illegible] concentrators are described below [illegible] the network. The control of message transmission between [illegible] concentrators is addressed in Section 3.1.3. Message priorities in NADIN are [illegible] Appendix [illegible].

- NADIN Concentrator [illegible] accepts information from terminals, breaks the information [illegible] frames [illegible] the frames to the switch. The concentrator [illegible] conversion, speed conversion and buffering [illegible] heading and a Communications Control Field [illegible] passing through the concentrator. In the special case of FSAS, in which both the [illegible] and the [illegible] are intelligent nodes, there are several ways to [illegible] tasks of adding NADIN headings and [illegible] and NADIN must be addressed by the respective implementation [illegible]. The [illegible] of frames from concentrator to switch is assumed [illegible] (FCFS) basis (ICAO recommendations, [illegible]).

- NADIN Switch: The [illegible] only implicitly given in the NADIN specification. The prediction of message delays requires an explicit knowledge of how the switch processes messages [illegible] possibly many interpretations of the specification is given [illegible] Appendix H (See also Reference 27). An alternative mode of switch operation [illegible] Section 4.2.

  The switch assumes all the functions of the concentrator whenever it is connected to an external system. [illegible] performs the basic NADIN functions of acknowledgement [illegible] check and edit, routing, code and format conversion [illegible]. The processing delay of all these operations, except for [illegible] compared to waiting and transmission delays. Therefore, only the switch [illegible] is examined in detail.

  From the NADIN [illegible] output mechanism is interpreted as a sequence of steps, conceptually [illegible] as occurring in an "internal queue" and an "output queue". Figure 3.2 illustrates the steps outlined below:

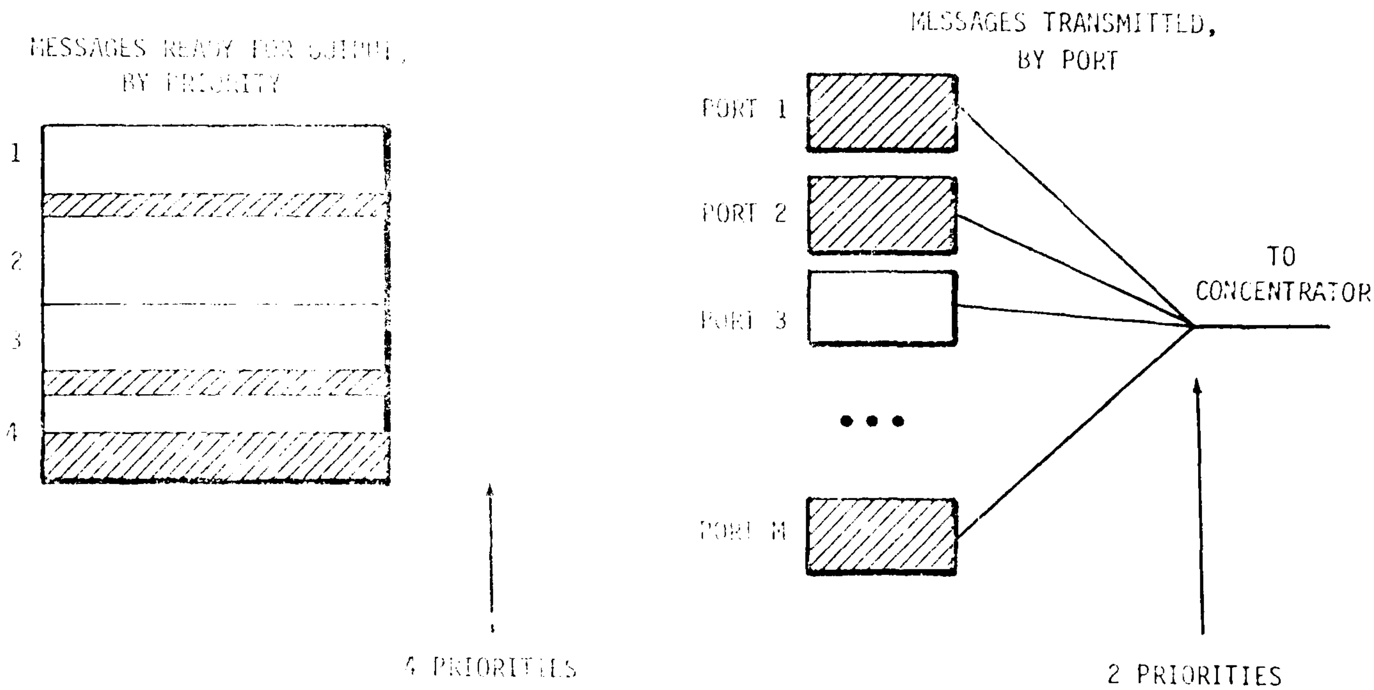


FIGURE 3.2: NADIN SWITCH OUPPUT OPERATION

Internal Queue:

- messages are stored in some type of mass storage (e.g., disk).

- the switch pulls a message from mass storage into the output queue whenever all available frames in the output queue are serviced; messages are taken according to four levels of priority and on a First Come First Serve (FCFS) basis within each priority class (see Appendix F for priorities).

Output Queue:

- messages entering the queue are either tagged by the switch as actively transmitted messages or transferred to a special output buffer,

- frames of these messages are interspersed for transmission, as follows: (1) the switch sends the subsequent frame in the same message if the concentrator is ready to accept it, (2) if the concentrator cannot accept a frame going to the same output port, the switch looks for frames going to other output ports. The next frame sent is chosen according to two levels of link priority and by cyclically checking messages going to all concentrator output ports, (3) if there is no frame in the output queue which the concentrator can accept, the switch brings a new message from the internal queue to the output queue.

This switch discipline is one of possibly many similar interpretations of the NADIN specification (see Appendix H for an explanation of the rationale supporting the above interpretation of switch operation). The outlined switch discipline is used in the next chapter as a basis for the queueing model of the switch to concentrator line. Message delays obtained on this basis are representative of delays obtained using any other interpretation of switch discipline consistent with the NADIN functional specification. The delays that NADIN messages experience using this service discipline become too large after the introduction of FSAS traffic. Three alternative solutions to this problem, including a modified switch discipline, are given in Section 3.3.

3.1.3 NADIN Protocols

Protocols are the rules which control information transfer between computer systems. The identification of NADIN's protocols is necessary to (1) analytically model NADIN and obtain delays and (2) determine the compatibility of the FSAS and NADIN systems. Sections 3.4 and 3.5 discuss these issues in detail on the basis of the definition of NADIN's protocols given here.

NADIN protocols are the rules which control message transfers (message level protocol) and frame transfers (link-level protocol) flowing to or from NADIN nodes. Also, the physical level protocol governs the mechanical, functional and electrical characteristics of these transfers. In addition to the message, frame and physical protocols, there are rules which restrict the flow of data between a switch and concentrator. Flow control between a switch and AWP, may be needed and could be implemented at the frame or message levels or some intermediate level.

NADIN's Physical Level Protocol - The physical level protocol determines the electrical characteristics of the interface between nodes (voltage levels, balanced/ unbalanced, synchronous/asynchronous) and the mechanical and functional characteristics (cable distances, connector pins, etc.). The protocol to be used by NADIN are described in the EIA Standards RS-422 and RS-449 (Reference 24). These standards allow transmission rates of the order of 100 Kbits/sec at distances of up to 4000 feet (1.2 Km) without need for modems.

NADIN's Link Level Protocol - The link level protocol controls the transmission of frames (message segments) between two nodes. It does not control the end to end frame transfer through the network (which may encompass one or more links). The link protocol used by both NADIN and FSAS is the "Advanced Data Communication Control Procedures" (ADCCP) specified in Reference 25 and summarized in Appendix J. Briefly: the data stream, composed of actual message content and message protocol data, is broken into frames of at most 2000 bits. The transmitting node adds control, addressing and error correction bits to the frame, as well as flags marking the start and end of a frame, adding an extra 48 bits to the data. There is also a Communications Control Field (CCF) inside each ADCCP frame. This field is included when an information or network management message transits NADIN

circuits between switching centers, between switching centers and concentrators, or between NADIN and other systems using high-level Data Link Control Field (DLCF) procedures (e.g., ADCCP is a DLCF procedure). The CCF contains all information required for correct message handling after the message has "cleared" the DLCF function. The length of the CCF varies from 5 to 7 octets (40 to 56 bits). This leaves 1944 data bits in each ADCCP frame. Message delays are slightly increased due to the link protocol overhead (Section 3.4). The compatibility of FSAS and NADIN is achieved by using the same protocol. This common protocol (ADCCP) could be used to control the flow of data between AWP's and NADIN switches.

<u>NADIN's Message Level Protocol</u> - The message level protocol consists of the information added to a NADIN message to instruct the switches or concentrators on the routing and processing required by the message. The information in a NADIN message is described at length in the NADIN specification and summarized in Appendix J.

The NADIN message consists of a maximum of 16 ADCCP frames, each with a usable information field of 1944 bits (243 characters). The NADIN message therefore could have a maximum of 3888 characters, including the message heading. However, to allow compatibility with the WMSC message format, the length of a NADIN message is restricted to a maximum of 3700 characters.

Table 2.1 on page 22 lists the different types of management information in the heading of a NADIN message. The impact of NADIN message overhead on delays is considered in Section 3.4 and the interface of NADIN and FSAS at the message level in Section 3.5.

<u>Data Flow Control Between FSAS and NADIN</u> - The transfer of large files between the AWP and FSDPS gives merit to the concept of the control of data flow between the AWP's and the NADIN switches (Section 3.3). This flow control can consist of ADCCP frames or NADIN messages inhibiting transmission of messages from the AWP. NADIN messages are preferrable since they allow the inhibition of only selected messages (e.g., file messages). The impact of data flow control on the size of buffers is considered in Section 3.4.

Data Flow Control Between NADIN Switches and Concentrators - NADIN is a versatile network which accommodates input/output ports of speeds from 75 bps to 9600 bps. Frames destined to a low speed output port can arrive at a concentrator faster than they can be retransmitted, and create a backlog of frames at the concentrator. The concentrator prevents this backlog by signaling the switch not to send any further frames to a given output line until the line is free. This flow control mechanism affects the calculation of message delays and creates interframe delays between segments of the same message (Section 3.4). It is assumed in the queueing model that the concentrator will hold at least two frames going to the same output port, one under transmission and the other in store, before requesting the switch to withhold transmission. (This buffering reduces the occurrence of interframe delays).

The method used to implement flow control between switches and concentrators has no impact on delays in NADIN. This delay is entirely determined by the output port speed. The concentrator can send NADIN network control messages to prevent the switch from sending further frames to the same port. NADIN messages can specify which concentrator output port is busy more easily than link level commands.

3.1.4 NADIN Traffic and Response Time Requirements

The initial NADIN users are the Service B network and the FAA controlled portion of AFTN (National AFTN). The traffic statistics of these initial users are given in Appendix Z of the NADIN specification. The initial NADIN traffic is further specified in the next chapter by adding protocol overheads to the raw traffic data of Service B and AFTN given in the NADIN specification. The maximum allowable delays of messages are also given in the NADIN specification and listed in Section 3.4.3.

3.2 FSAS STRATEGIC TRAFFIC REQUIREMENTS

The quantitative FSAS traffic requirements are the FSAS message origins, destinations, lengths and arrival times. Strategic requirements are the qualitative statements defining the scope of quantitative traffic requirements and the assumptions made to obtain them. Strategic requirements are especially important in this study because both the FSAS and NADIN are future systems. As a result it is necessary to make assumptions at almost

every step of the study: on the services FSAS requires from NADIN, the level of performance, the stage of FSAS implementation at a given time and the corresponding stage of NADIN implementation, the impact of the integration of other FAA communications in NADIN, etc. This section presents the determinate aspects at the start of the study, the assumptions made to resolve them, and the constraints determining the FAA environment.

This section briefly introduces the Flight Service Automation System and the non-automated Flight Service Station (FSS) system it replaces. It then defines the scope of traffic requirements [illegible] in the next chapter, and determines the FSAS subsystems considered in this study. Section [illegible] the effect of time on traffic requirements. This includes the comparative schedules of FSAS and NADIN implementation, the future traffic forecasts and the degree of completion of FSAS at various future years. Finally, the performance that FSAS requires is [illegible].

3.2.1 Description of FSAS

The user's end of the FSAS [illegible] flight service stations (AFSS) which serve, for the most part, [illegible]. The processing components of the FSAS are 23 Flight Service Data Processing [illegible] (FSDPS) and [illegible] Aviation Weather Processors (AWP). The data traffic of FSAS is [illegible] weather information plus some aeronautical data. Readers not [illegible] FSAS environment can consult Appendix A for more details.

3.2.2 Scope of FSAS Traffic Requirements

This report considers [illegible] communications irrespective of whether they are going to be integrated in NADIN or not, but with emphasis on the former. The possible wider future integration of FSAS communications in NADIN motivates this large scope of coverage. The choice of NADIN's level of support to the FSAS data communications is made in the FSAS specification: NADIN will provide the FSAS internal backbone connections between AWPs and FSDPSs, and FSAS external connections to the WMSC, ATCSCC, ARTCCs and NFDC; in the immediate future NADIN will not support the local extensions of the FSAS consisting of Automated Flight Service Stations (AFSS), Weather Radars and DUATs. This report [illegible] FSAS that limits the analysis of FSAS impact on NADIN [illegible].

The FSAS information collected is that needed to model the impact of FSAS traffic on NADIN: node functions, node locations and traffic.

FSAS Node Functions: The function of each node determines the type of traffic going to and from the node (e.g., batch or interactive). The Aviation Weather Processors (AWPs) receive raw weather data from non-automated FAA weather stations and from the National Weather Service (NWS) through the WMSC. They also receive Notices to Airmen (Notams) from the NFDC and air flow control messages from the ATCSCC. The AWP's process all the raw data and send the processed version to the FSDPS's, as well as the unprocessed version. The FSDPS's act as data banks with retrieval and assembly capabilities and service the AFSS's. Thus, the AWP to FSDPS traffic mainly consists of one way message transmission whereas the AFSS to FSDPS traffic is interactive in nature. Appendix B contains a detailed description of all FSAS nodes and external systems to which they are connected.

FSAS Node Locations: The FSAS backbone configuration is a replica of NADIN's and this simplifies the study of the impact of FSAS traffic on NADIN. Specifically, the two AWPs are colocated with NADIN switches at Atlanta and Salt Lake City. Similarly, the FSDPSs are colocated with the NADIN concentrators at the 23 Air Route Traffic Control Centers (ARTCCs). With this colocation, the AWP to AWP traffic appears on the NADIN switch to switch link and the FSDPS to AWP traffic on the NADIN concentrator to switch links. So, the precise locations of FSDPSs are not required to analyse the impact of FSAS on NADIN. However, they are needed for the cost evaluation of a contingency FSAS communication plan not using NADIN.

The locations of the AFSSs and DUATs are not yet known. For reference and future planning purposes, a tentative list of AFSSs is given in Appendix E, based on projections of Flight Services Stations likely to be automated.

The detailed documentation of the location and function of FSAS nodes and external systems is in Appendix B. The conjectures and predictions made to obtain that information are given in the next section (3.2.3) and the next chapter (Section 4.1).

FSAS Traffic: The analytical modeling of NADIN and the prediction of message delays requires knowledge of the length of messages (equivalently, the transmission time over

a line of known speed) and arrival times of messages. The FSAS specification covers most of the FSAS backbone network traffic statistics. In the present study, in addition, the individual FSDPS to AFSS traffic is documented and some of the FSAS backbone traffic is updated (schedules, numbers of messages per hour). The local AFSS traffic is predicted using a tentative list of future AFSSs by the FSAS program and predictions of FSS services made by FAA's Aviation Policy office (References 9, 12 and Appendix E). The next chapter documents how raw traffic statistics are obtained and processed to a form usable in NADIN's queueing model (Section 4.1).

3.2.3 Prediction of Future FSAS Requirements

FSAS and NADIN are not in place yet and this makes it difficult to assess their mutual impact: there is no schedule for FSS automation and FSDPS installation and the number of FSDPS that will be in place at the start of NADIN is not known. Another issue is the future increase of FSAS data traffic. While these issues cannot be definitely resolved, they can be avoided by consistently assuming maximum FSAS loading on NADIN. This approach results in a conservative design of the NADIN enhancements needed for FSAS.

When NADIN starts, it is assumed that the AWPs and some FSDPS will be in place, and so there will be FSAS traffic on the NADIN switch-switch link and on some of the switch-concentrator links. If this traffic creates a need for a NADIN enhancement then this enhancement should be applied to all NADIN (e.g., increase the line speed of all switch-concentrator connections). This is justified by the concordance of FSAS and NADIN centralized architectures, which makes it unpractical to plan enhancements of similar links in a piece-meal fashion, waiting for the gradual implementation of FSDPSs.

The FSAS traffic is forecasted at three key dates: 1983, 1988 and 2000. The year 1983 is the earliest date at which the implementation of Model II FSAS is due to start (installation of AWPs). The year 1988 is the earliest date at which all 23 FSDPSs and 63 AFSSs can be in place. The year 2000 is, tentatively, the earliest date at which the manual FSSs will be completely phased out. This schedule deliberately assumes a rapid pace of automation for the FSS system in order to obtain FSAS traffic estimates which are on the safe side. There are two types of FSAS traffic: weather related, which does not significantly change with time (except for the introduction of the AFOS weather maps) and air traffic related, which increases with time. As a result, the AWP to FSDPS traffic statistics given in the FSAS specification are assumed constant with the exception of NFDC

Notams. The local FSDPS to AFSS traffic is considered variable and computed using the Aviation Policy Office (AVP) forecasts of FSS activities. The method of processing these forecasts is given in Appendix E and consists of assuming FSS traffic will gradually be diverted to the nearest automated site.

3.2.4 Relation of FSAS Integration Study in Other FAA Programs.

FAA programs like FDEP and Flow Control may soon decide to use NADIN for their data communications. In such a case, NADIN may require node enhancements and line speed increases beyond those necessary for the integration of FSAS. The specification of such NADIN changes is beyond the scope of this report. However, the separate studies made by NADIN of FDEP, Flow Control and NFDC provide, in conjunction with this report, the basis for an integrated study of NADIN's needed enhancements. This study will be facilitated by the similar traffic requirements formats adopted in each of the reports.

3.2.5 FSAS Performance Requirements

FSAS performance requirements consist of the quality of service expected from NADIN. They are measured by: network availability, total network delay and accuracy of transmissions. Since none of these requirements are quantitatively listed in the FSAS specification, the interpretation of NADIN's performance results for FSAS is mainly qualitative.

Network availability is the percentage of time NADIN is in operating condition. The NADIN specification requires a high availability for switches and concentrators (99.98%). NADIN also has semi-automatic dial-up capability to provide protection from (1) catastrophic failure of a message switch, (2) catastrophic failure of a concentrator, (3) failure of trunks. In the event of a switch failure, the other switch will be capable of assuming the functions of the entire network. All the stringent requirements on NADIN availability were designed to ensure uninterrupted transmission of messages directly related to air safety. Since weather information generally has less stringent requirements it is safe to assume that the availability requirements of FSAS will be automatically satisfied.

Total network delay is the time interval from when the message is ready for network entry at a user circuit until the last character of the message has been transferred to the appropriate destination user. The FSAS specification does not specify the total network

delay requirement for FSAS messages. However, since weather data has less stringent requirements than air traffic data, and since there is no interactive traffic in the FSAS backbone network, the average delay requirement of 2 seconds listed in the NADIN specification is considered sufficient.

Accuracy of transmission is measured by the percentage of messages which are transmitted from user to user through NADIN with no errors. Again the FSAS specification does not specify the required accuracy. However, it is expected that NADIN will provide high accuracy through the use of conditioned lines for its backbone connections and through the use of a Frame Check Sequence (FCS) in each frame.

3.3 BASIS OF FSAS COMMUNICATIONS ALTERNATIVES

A preliminary investigation determined that the integration of FSAS communications into NADIN is the most economical approach. The use of a network of dedicated lines for FSAS is an alternative to be considered only on a contingency basis, if NADIN's implementation schedule slips. Three subalternatives to NADIN's use were generated as a result of a first pass at analysis of performance. All four alternatives are described in Section 4.2.

The current FSAS contingency plans call for the use of dedicated lines in case NADIN schedule slips. These plans form the basis for the contingency alternative. The three NADIN subalternatives consist of the use of 4.8, 9.6 or 19.2 Kbps lines between switching centers and concentrators. All were chosen so as to satisfy the delay requirements of the NADIN specification. In the first two cases the switches design must be such as to equally treat the FSAS and initial NADIN traffics.

For cost comparison, all alternatives assume that the FSAS data communication needs encompass all the continental U.S (CONUS). This assumption avoids the undeterminacies in the schedule of FSDPS installation and it is consistent with the present FAA contingency plan.

3.4 BASIS OF PERFORMANCE IMPACT ANALYSIS

The use of a detailed queueing model that was developed for this task demonstrates that NADIN can satisfy FSAS communication requirements over the range of all three NADIN alternatives. This model determines the end to end delays of FSAS messages and initial NADIN traffic through the network. It also determines the expected buffer

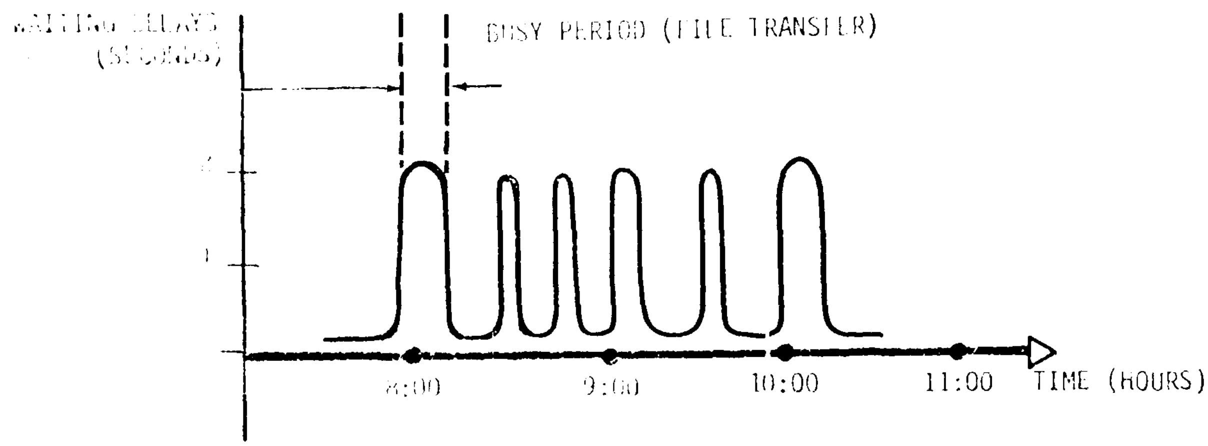


FIGURE 3.3: EFFECT OF FILE TRANSFERS ON DELAYS

occupancy at the switches and concentrators. The actual mathematical formulation of the model and its solution are given in the next chapter (see Section 4.3).

A preliminary analysis showed that the transfer of large files from an AWP to the FSDPSs creates a "busy period" which can last for up to 10 minutes every hour. During this busy period NADIN's performance is degraded (see Figure 3.3). Two separate models of NADIN are created to deal separately with busy periods and normal periods.

This section starts with the analytical models developed to predict delays and buffer requirements (Section 3.4.1). The inputs to the model (traffic statistics) and the operations done to use them in the model are discussed in Section 3.4.2. The outputs expected from the model (delays and buffer requirements) are defined quantitatively in Section 3.4.3. Section 3.4.4, which concludes this section, discusses the effect of switch-concentrator flow control and priorities on modeling.

3.4.1 Analytical Models to Predict Performance

Four analytical models determine delays and buffer sizes in NADIN: at times of FSAS file transfers and at times of normal operation, with two modes of switch message queueing for each. Each of these models is in turn composed of "sub-models" analyzing the various links in NADIN. One of these sub-models (M/G/1 queue) is commonly used, but the rest were developed specifically for this task.

The scope of analysis is limited to the lines connecting NADIN nodes (switches and concentrators) and excludes the modeling of message processing inside the nodes. This limitation is imposed by lack of present knowledge of the details of NADIN implementation. However, it is an acceptable limitation because nodal delays are typically one or two orders of magnitude smaller than line delays and may be ignored without significantly affecting overall results.

The analysis also considers NADIN links only on a generic basis. This is consistent with the initial NADIN traffic statistics given in the NADIN specification and with the FSAS traffic statistics given in the FSAS specification. These statistics represent the heaviest switch to concentrator traffic, and AWP to FSDPS traffic, respectively.

The sub-models used in the analysis are: (1) M/G/1 queue, (2) Round-Robin or Asynchronous Time Division Multiplexing (ATDM) queue, (3) deterministic queue, (4) $90^{\underline{th}}$ percentile delays of a G/G/1 queue, (5) buffer occupancy of a G/G/1 queue, (6) message interframe delays.

M/G/1 queue (Appendix K): An M/G/1 queue consists of a single utility which services users having exponential interarrival times and requiring service times with a general distribution (Markov arrivals, General service time, 1 server). In the context of NADIN, the utility is a switch or a concentrator, the users are messages and the service times are the transmission times messages over the lines leaving the switch or concentrator. This model has been solved by Khinchine and Pollaczek. (Reference 21).

Round Robin queue (Appendix M): The server of the queue has several classes of users and cyclically checks their need for service. In the context of NADIN, the server is the switch (see description of modified switch operation in Section 4.2). It sends at most one frame at a time to a concentrator output port and checks the other ports before sending another frame to the same port. This queue is solved by treating each of the paths from switch to concentrator output port as an M/G/1 queue and then solving for the total time the switch spends in a cycle. The analysis developed is only applicable when there is an uninterrupted stream of frames coming from the AWP (busy period).

Deterministic queue (Appendix N): A special model is developed to analyse the build-up of frames at a NADIN switch and the delays of FSAS messages at times of file transfers.

90th Percentile Delays (Appendix I): Kingman has obtained an approximation for the integral of the tail of the waiting time probability density function (pdf) of a G/G/1 queue. This result is used to obtain the 90th percentile delay of a frame going through several successive NADIN links.

Buffer Occupancy (Appendix I): The buffer needed to accommodate waiting frames in a G/G/1 queue at the 95th percentile level is readily computable from the results on 90th percentile delays. The model solved in this study gives the buffer space needed to accommodate the frames waiting in several G/G/1 queues. This result applies to a NADIN switch which services several concentrators.

Message Interframe Delays (Appendix P): Frames of a single message are interspersed with frames of other messages. The effects of flow-control between switches and

concentrators and the switch service discipline are incorporated in a model which gives the probabilities of interframe delays.

The combination of the various analytical queueing models briefly described above constitute a mathematical description of NADIN. The overall delay of a message in NADIN is obtained by adding message delays on various NADIN links, using different models for each link if needed. The addition of delays on links is based on an independence assumption: that the queue on each link is independent of queues on preceding links. While this assumption is strictly correct only in a few special cases it has generally been observed that idealized queueing models give results close to reality (Reference 19).

3.4.2 Inputs to Analytical Models

The inputs to all the queueing models used in this study are message length statistics, line speeds, and arrival time statistics. The models used assume either exponential inter-arrival times or continuous arrivals. The message length distributions (equivalently, service time distributions after dividing by line speeds) are general.

Since NADIN's delays must be computed at both normal times and at times of FSAS file transfers, two sets of statistics are used: (1) the normal traffic, consisting of all unscheduled message and (2) the busy period traffic, consisting of normal time traffic plus file transfers.

The traffic statistics are obtained from NAC's FSAS requirements analysis study (Deliverable C1) and from the NADIN specification (Reference 1). This information is given in Appendices C and D, respectively.

The various analyses and assumptions made to put traffic statistics in a form usable in the model are presented below.

Message Length and Service Time Statistics: The "service" time, or transmission time of a message over a line, is equal to the length of the message divided by the line speed. This linear relationship allows to speak interchangeably of message length or service time statistics.

The various classes of traffic in NADIN have different message length (or service time) distributions. The most common are the uniform, biased exponential and normal

distributions. It is not possible to solve the M/G/1 queueing model with all these distributions present simultaneously. Instead, the distributions are all replaced with a normal distribution having the same average and standard deviation. This substitution thus replaces the weighted sum of several functions with a normal (bell-shaped) function, an intuitively reasonable assumption. This substitution may affect $90^{\underline{th}}$ percentile delay calculations but has no effect on the calculation of average waiting times.

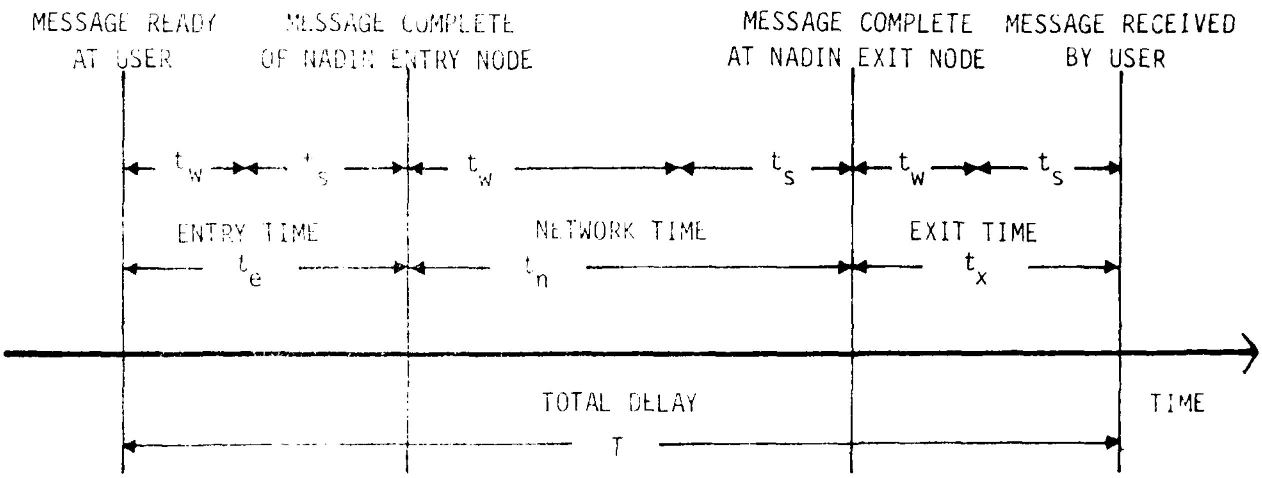
The NADIN protocols (ADCCP, NADIN message) affect the message length distribution through the addition of control characters (See Appendix J). The ADCCP protocol results in 6 extra octets, the Communication Control Field (CCF) in an overhead of 5 octets and the NADIN message header adds 20 to 63 octets. These figures are added to the message length to obtain the statistics used as input to the queueing model. Another effect of the ADCCP protocol is that the message unit in NADIN is a frame with a maximum of 2048 bits rather than a message. Appendix G solves the problem of obtaining frame statistics from message statistics. The key assumption is that frames obtained from breaking up a long message are either full frames or partial frames having a uniform length distribution.

Message Arrival Statistics: The arrival of all unscheduled messages is assumed to be Markovian (exponential interarrival times). A Markovian process has the property that arrivals are memoryless: a message is equally likely to arrive at any time, independently of previous arrivals. This property is a good description of a real network like NADIN where there are enough message sources to make message arrivals unrelated. In those few cases where messages exceed one frame in length, the arrival of frames is still considered Markovian, as a working assumption.

The file transfers from the AWP to the FSDPSs create a deterministic continuous arrival of frames. A separate analysis is made in the next chapter to deal with this type of arrivals.

3.4.3 Outputs of Analytical Models

The analytical modeling of NADIN yields information on network performance. The outputs of the model are the average delays of messages, the $90^{\underline{th}}$ percentile delays, and the buffer occupancies at the switches and concentrators.



t_w = TIME WAITING FOR TRANSMISSION

t_s = TRANSMISSION TIME (SERVICE TIME)

FIGURE 3.4: DELAYS OF MESSAGES IN NADIN

Average Delays: The following definitions are used in expressing delay (from NADIN specification, Z-5.2), and illustrated in Figure 3.4. The delay on each link has two components: transmission delay and waiting delay. The transmission delay is equal to the length of a frame divided by the line speed. The waiting delay is the time a frame waits for the switch or concentrator's attention.

(a) The total delay T of a message is the interval of time from when the message is ready for network entry at a user circuit until the last character of the message has been transferred to the appropriate destination user.

(b) The entrance delay t_e of a message is the interval of time from when the message is ready at a user until the last character of the message has been received at the network entry point.

(c) The network delay t_n of a message is the interval of time from receipt of the last character of the message at its network entry point until the first character of the message is transmitted to the destination user.

(d) The exit delay t_x is the interval of time for transferring a message from its network exit point to the destination user.

From these definitions it follows that:

$$t = t_e + t_n + t_x$$

This expression is used in the next chapter to obtain the overall average delay characteristics of NADIN after superimposition of FSAS traffic.

90th Percentile Delays: The $90^{\underline{th}}$ percentile delay over a path in NADIN is the delay not exceeded by 90% of messages over that path. The $90^{\underline{th}}$ percentile delay is computed for the waiting time only and added to the average service time (or transmission time) to obtain the overall 90^{th} percentile delay. This definition is justified by the fact that the waiting time is determined by the network and it is NADIN's responsibility to keep it to a minimum. The transmission time, on the other

hand, is determined by the user, who must expect longer transmission times for longer messages. The definition of $90^{\underline{th}}$ percentile times given above is further justified by the fact that messages which require short overall transmission delays are usually short themselves.

The calculation of $90^{\underline{th}}$ percentile delay is obtained by using a bound on the tail of the waiting time distribution (Reference 22). Appendix I includes a derivation of the $90^{\underline{th}}$ percentile delay over successive links.

Buffer occupancy: The switches and concentrators hold in memory the messages which cannot be immediately processed or outputted. Basically, all messages are accepted and, if the core memory of a switch or concentrator is filled, the messages are put onto some low speed storage device and later retrieved, with accordingly large delays. It is necessary to make estimates of the amount of on-line buffer needed to accommodate messages queueing up for transmission and also to estimate the probabilities that the on-line buffers will overflow. This study calculates the amount of buffer space necessary to ensure that 95% of all messages can be held on-line. Appendix I includes a derivation of the buffer space needed when a single node (e.g., switch) services several links. Also, instead of calculating the buffer space needed for a probability of overflow less than 5%, the analysis can be used to predict overflow probabilities when a certain buffer size is chosen.

NADIN Delay Requirements: The NADIN specification requires maximum network delays for three situations: normal traffic, zero traffic (i.e., only transmission and processing delays are present) and worst case traffic (100% extra traffic). Briefly, the delay requirements are that the average delay from a concentrator served by one switch to a concentrator served by another be less than 2.0, 1.2 and 4.0 seconds, respectively. For first level priority the delays should not exceed 1.5 seconds for normal traffic and 1.7 second for worst case. The 90th percentile delays should not exceed 4.0, 1.8 and 8.0 seconds in the three cases, respectively.

3.4.4 Special Issues in Modeling

Several aspects of NADIN described in Section 3.1 affect the model of NADIN: priorities, concentrator control of messages coming from the switching center, and flow

control between a switching center and an AWP. These issues are dealt with on an ad-hoc basis in the next chapter and appendices. The major assumptions concerning each issue are listed below:

Priorities in NADIN: Messages are assigned four priorities in NADIN and are chosen for output according to these priorities on a first come first served (FCFS) basis. Once messages are in the output buffer of a switch or a concentrator they are then transmitted one frame at a time with two levels of link priority. The first link priority is the same as the first internal priority. The second link priority is assigned to messages of internal priorities 2, 3 and 4.

The queueing model for NADIN is more complex due to the presence of priorities but some simplifying assumptions are made. In general, the effect of priorities on delays is to diminish the delays of high priority messages at the expense of low priority messages while keeping the overall average delay the same. In the case of NADIN traffic, the overwhelming majority of messages has second link priority and therefore the average delay does not differ significantly from the delay of second priority messages. As a result, delays of second priority messages are assumed equal to average overall delays. The calculation of delays for first priority messages is done separately. A conservative estimate is obtained by considering that a first priority message waits at most for the completion of transmission of one frame from another message.

Switch-Concentrator Flow Control: The delays of messages are conservatively estimated by ignoring the flow control between switches and concentrators. Flow control creates a continuous transmission of frames. The analysis used in this study assumes independent waiting times on successive links and the total computed delay is higher than a delay computed taking into account continuous frames transmission. For performance evaluation, the probabilities of interframe delays are obtained.

A switch sends a frame to a concentrator only after receiving indication that the destination concentrator output circuit is about to be free (see Section 3.1.3). This procedure can result in a delay between successive frames of the same message, especially with a switch discipline which intersperses frames of several messages. To prevent this delay, the concentrator uses multiple buffering. That is, the concentrator

has memory space for one or more frames other than the frame being transmitted, so that the transmission of frames appears to be continuous at the concentrator output port. This continuity is achieved by the simultaneous transmission of a frame over the concentrator output line and the transmission of the next frame over the switch to concentrator line. It is conceivable of course, that the delay of a frame at the switch is larger than the time it takes to transmit the previous frame on the low speed output line. In that case, there will be a delay between successive frames of a single message. Since this occurrence is rare, the magnitude of interframe delays are not computed. However the probability of interframe delays is obtained in Appendix P. Following is a brief discussion of three situations encountered by a frame arriving to the switch (See Figure 3.5):

(a) A frame arrives at the switch and finds the concentrator output port to which it is destined idle. The delay of this frame is equal to the time waiting for the switch attention plus the times of transmission over the switch to concentrator line and over the output concentrator line.

(b) A frame arrives at the switch and finds the concentrator output port to which it is destined busy and possibly finds waiting frames which are going to the same destination. However, the time it takes to transmit the previous frame over the low-speed port output line. In this case the delay introduced by the switch is irrelevant and the delay experienced by the frame is the same as that it would have experienced waiting for transmission over the low-speed output line is greater than the interframe delay due to waiting for switch service and for transmission over the switch to concentrator line. (Effectively, the switch is an extension of the concentrator buffers).

(c) The arriving frame finds the same situation as above, but this time the interframe delay may exceed the time it takes to transmit a single frame over the low-speed output line. The excess times must then be summed over all preceding frames and added to the queueing time the frame would experience if only waiting for transmission over the low speed output line. Although this is an unlikely occurrence, it is used for delay calculation to ensure conservative results. The probability of interframe delays is obtained in the next chapter.

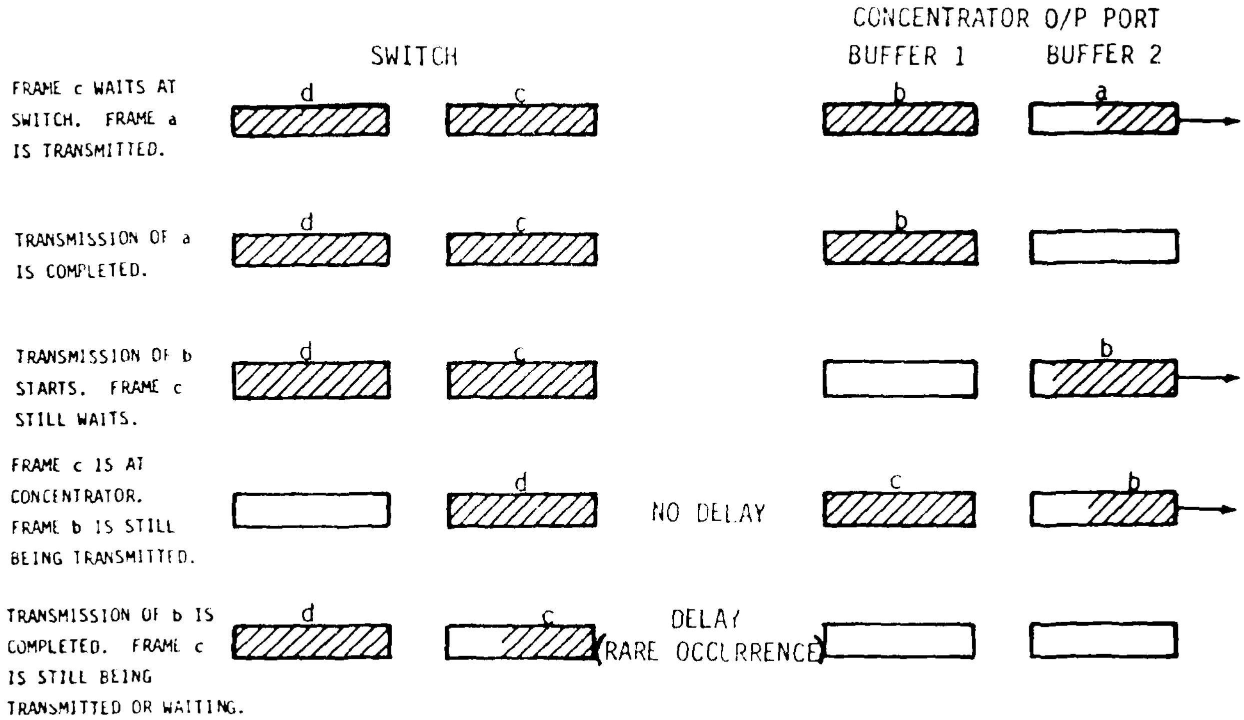


FIGURE 3.5: PREVENTION OF INTERFRAME DELAYS BY BUFFERING

AWP-NADIN Switch Flow Control: Flow control as proposed in this study reduces the amount of buffer space needed at the switches and improves the nework response time experienced by unscheduled FSAS messages at times of file transfers. This study assumes no flow control between AWPs and NADIN switches and calculates the backlog of frames at the switch. The study then goes on to find that if flow control is implemented, the backlog of frames at a NADIN switch effectively remains at the AWP.

3.5 BASIS OF INTERFACE ANALYSIS

The review of interface modes in the NADIN and FSAS specifications is the basis for the analysis of compatibility. Both specifications recommend the balanced EIA-RS-449 standard for electrical and mechanical interface and the Advanced Data Communication Control Procedures (ADCCP) for link control (References 24, and 25).

The NADIN message structure is described in the NADIN specification and in Appendix C of the FSAS specification (References 1 and 2) the NADIN message structure of FSAS data is required.

The speed of interface lines between AWPs and NADIN switches and between FSDPSs and NADIN concentrators are not specified. The speeds are recommended in this study on the basis of NADIN-FSAS interface analysis.

3.6 COST IMPACT ANALYSIS

The present value cost comparison of the NADIN and non-NADIN alternatives illustrates the cost effectiveness of using a network utility that has:

- spare capacity,
- expandable capacity within network architectural framework,
- diverse connectivity capability.

Each of the NADIN alternatives have diverse connectivity capability. NADIN Scenario 1 (4800 b/s) illustrates the tremendous savings available if a network has spare capacity. NADIN Scenarios 2 and 3 (9600 and 19,200 respectively) illustrate the significant savings available if a network has expandable capacity within its architectural framework. These

Cost comparisons are valid as long as NADIN is capable of satisfying the performance requirements of FSAS. These comparisons become invalid if incremental additions of capacity no longer satisfies the incremental performance demands of additional traffic. The point in time that the NADIN architecture becomes saturated is dependent upon many variables (such as implementation time frames of FDEP, Flow Control, and NFDC). For this reason the comparison period does not extend beyond three years. Clearly, a leased line alternative is cost inferior to any of the NADIN alternatives during this period.

3.6.1 Fixed and Recurring Costs Used In Present Value Analysis

Determination of fixed and recurring costs of each NADIN support scenario and the non-NADIN alternative shows the cost superiority of NADIN's use for FSAS. This cost superiority is due to the massive recurring cost of the non-NADIN alternative and the consideration of initial NADIN acquisition costs as a sunk investment. The fixed and recurring costs for the various alternatives are:

	Fixed Cost ($)	Recurring Cost ($ per month)
NADIN SCENARIO 1	91,000	0
NADIN SCENARIO 2	278,286	322
NADIN SCENARIO 3	671,255	9,445
Leased Line Alternative	358,693	57,083

The large recurring cost of the leased line alternative is a result of the high number of dedicated leased telecommunications facilities necessary for the extensive FSAS connectivity requirements.

3.6.2 Key Costing Assumptions for NADIN Alternatives

The key assumption made in costing NADIN alternatives is that NADIN backbone service is "free", except for the specific upgrades necessary to accommodate FSAS traffic. This assumption is reasonable because:

- NADIN acquisition costs are sunk costs, i.e., expended regardless of use,

- initial use of NADIN capacity will be very low i.e., excess capacity will be available,

- FSAS is most likely to be the first addition to the basic NADIN,

- other candidates will come later but with uncertainty as to when.

The cost of integration is therefore a marginal cost. The cumulative effect of other candidates is to be considered by a separate task. NADIN marginal costs shall be those above and beyond the original NADIN acquisition. The marginal cost deals with specific modifications to NADIN's initial planned state with regards to:

- line capacity,

- concentrators,

- switches.

It is also assumed that all Continental U.S. ARTCC's are active FSAS users, i.e., have FSDPS's, and that NADIN must support this communications need.

3.6.3 Key Costing Assumptions for Non-NADIN Alternatives

Unlike NADIN alternatives, the leased line alternative cost analysis assumes acquisition of dedicated communication capability specifically for FSAS and with no sharing. It is assumed that this leased line alternative, referred to as a communications contingency plan, is capable of satisfying the technical requirements of FSAS. In addition, FSAS program costs necessary to insure proper operation with the contingency plan (e.g., network management and technical control) are not addressed. All hardware associated with the communications facilities, e.g., modems, are assumed to be leased. As in the case of NADIN alternatives, it is assumed that all CONUS ARTCC's are active FSAS users.

CHAPTER 4

METHODOLOGY

Forecasting, queueing theory and cost-accounting methods are used in the analysis of future FSAS requirements, NADIN performance and cost impacts, respectively.

4.1 REQUIREMENTS ANALYSIS MODELING

Detailed models for estimating the total composite FSAS traffic to the year 2000 are developed and presented. Models are also developed to estimate the number and locations of FSDPSs and AFSSs in 1983, 1988 and 2000.

FSAS Node Locations and Numbers: The FSAS consists of AWPs, FSDPSs and AFSSs. Since NADIN will only support AWP and FSDPS traffic for now, it is not necessary to know the sites of AFSSs. There is even no need to determine the locations of FSDPSs implemented first because any NADIN enhancements will be done all over the network. However, the documentation of FSDPS and AFSS locations has been done at an early stage of this study and it is included in Appendices B and E for reference. These appendices contain tentative lists of 14 FSDPSs and 41 attached AFSSs to be all in place by 1988 at the earliest. The information may be of use for future planning of local FSDPS to AFSS communications, independent of the use of NADIN. The methods of forecasting the implementation schedules and locations of AFSSs are explained in Appendix E. A description of all FSAS nodes and connected systems is given in Appendix B.

FSAS Traffic: The FSAS specification contains all the basic information on traffic. The extra data and assumptions included in this study are:

- Hourly Flight Plan traffic between FSDPS and ARTCC is obtained from yearly traffic forecasts of FSS activity,
- FSDPS to AWP traffic (Notams, Pilot Reports and Surface Observations) is assumed to be 10 % of the corresponding AWP to FSDPS traffic,

- Hourly number of Notams each hour are obtained from forecasts of yearly number of Notams,

- Busy hour traffic is obtained by multiplying yearly traffic figures by 0.00035.

- The length of weather messages from WMSC to AWP is assumed doubled after formatting by the AWP,

- The hourly number of AFOS graphics is changed from 36 to 86,

- The number of certain emergency weather reports per hour (tropical advisories, weather warnings) provided by the Aviation Weather Branch of NWS.

The traffic statistics consist of the probability density functions (pdf's) of message length and arrival times. These concepts and their application are defined in Appendix K.

A large amount of processing is done to traffic statistics:

- NADIN traffic units are frames as opposed to messages. Appendix G analyses the operations which are made to transform message statistics into frame statistics.

- The various amounts of overhead due to NADIN message and link protocols are analyzed in Appendix J.

After adding protocol overhead to raw traffic data and substituting frames for messages, the FSAS and initial NADIN traffic is allocated to the various links it appears on. For example, a flight plan from an FSDPS to the colocated ARTCC is counted twice: once on the concentrator to switch link and once on the switch to concentrator link. This analysis is carried out in detail in Appendix L. Figure 4.1 shows the generic NADIN links and Table 4.1 summarizes the traffic on these links.

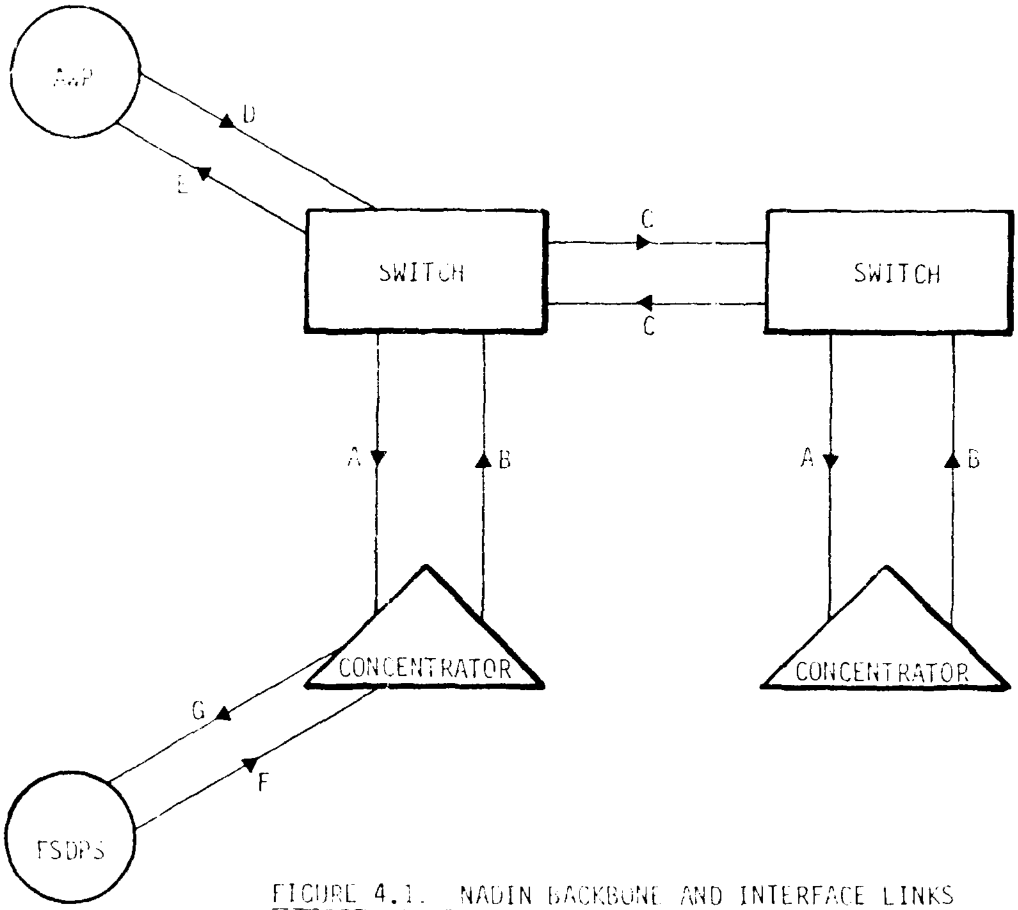


FIGURE 4.1. NADIN BACKBONE AND INTERFACE LINKS

LINK	Line Speed	NADIN overhead (Kbit)	$\bar{t}_s$ (sec)	$\bar{t}_w$ (secs)	t_q (secs)	s_0 (1/sec)	t_{s_0} (secs)	λ (frames/sec)	ρ
A: Switch to	4.8	0.504	0.300	0.216	0.516	3.03	0.760	1.839	0.551
Concentrator	4.8	0.160	0.251	0.122	0.373	4.44	0.519	1.704	0.428
	9.6	0.504	0.150	0.033	0.183	11.79	0.195	1.839	0.276
	9.6	0.160	0.126	0.022	0.148	14.51	0.159	1.704	0.214
B: Concentrator to	4.8	0.504	0.252	0.027	0.279	8.83	0.261	0.582	0.147
Switch	4.8	0.160	0.180	0.015	0.195	11.60	0.198	0.582	0.104
	9.6	0.504	0.126	0.006	0.132	22.12	0.104	0.582	0.073
	9.6	0.160	0.090	0.004	0.093	27.89	0.083	0.582	0.052
C: Switch to	9.6	0.504	0.155	0.039	0.194	10.88	0.212	1.988	0.308
Switch	9.6	0.160	0.130	0.025	0.155	13.94	0.165	1.855	0.240
D: AWP to Switch	9.6	0.504	0.156	0.022	0.178	14.16	0.533	1.257	0.197
	9.6	0.160	0.138	0.016	0.153	16.47	0.140	1.132	0.156
E: Switch to AWP	9.6	0.504	0.148	0.026	0.174	13.02	0.177	1.495	0.222
	9.6	0.160	0.126	0.018	0.144	15.60	0.148	1.364	0.172
F: FSDPS to	4.8	0.504	0.260	0.010	0.270	11.47	0.201	0.222	0.058
Concentrator	4.8	0.160	0.187	0.006	0.193	14.24	0.162	0.222	0.042
G: Concentrator	4.8	0.504	0.296	0.123	0.417	4.32	0.533	1.403	0.413
FSDPS	4.8	0.160	0.251	0.078	0.329	5.60	0.411	1.278	0.321

$\bar{t}_s$: mean transmission time

$\bar{t}_w$: mean waiting time

$\bar{t}_q$: queueing time (transmission & waiting)

t_{90}: 90th percentile delay

ρ: utilization of line

TABLE 4.1: TRAFFIC THROUGHPUT AND DELAYS ON NADIN LINKS (between file transfers)

4.2 DESCRIPTION OF COMMUNICATIONS ALTERNATIVES

The detailed description of three NADIN scenarios and a MITRE recommended contingency plan are presented. In the first two NADIN scenarios, the switch queueing procedure is a modification of the queueing procedure presented in Section 3.1. The line speeds between switches and concentrators are 4.8 and 9.6 Kbits/sec. The third NADIN scenario keeps the switch queueing procedure unchanged but the switch to concentrator line speed is increased to 19.2 Kbits/sec. This speed was shown from a first pass analysis to be necessary to bring message delays within the limits set by the NADIN specification.

> Modified Switch Queueing Procedure: In the switch output queueing procedure described in Section 3.1, the switch sends a frame to the concentrator whenever the concentrator output circuits currently transmitting frames can receive more traffic, because of their lower speed. This method has the drawback of allowing a high speed output port to monopolize the switch to concentrator line. The FSAS, in particular, has a high speed interface (4.8 Kbits/sec or more) between the FSDPS and the NADIN concentrator and, at times of file transfers, the switch will keep sending successive frames of a 16 frame message with no chance to consider messages waiting for initiation of transmission to other concentrator output circuits.

The modification in the switch service discipline consists of interleaving single frames from each message destined to an output port which is idle. The switch thus cycles through a set of virtual queues, one for each of the concentrator output circuits. Referring to Figure 3.2 on page 29, this means that on the right, and for each output port at the concentrator, there is a buffer space containing a message destined to that port, if available, regardless of the presence of other messages in the output buffer. Clearly, this remedies the blocking of messages of priority 1, 2 and 3 by FSAS file messages of priority 4, since the delay imposed by FSAS messages is the time to transmit one frame rather than 16 frames (It must be noted that an FSAS message of priority 1, 2 and 3 will still have to wait for the transmission of a full 16 frame message, since both are going to the same port and aborting partially transmitted messages is not envisioned). The modified switch discipline outlined above will not in itself ensure the continuity of messages, as was the case before modifications, since the switch may send several frames destined to different ports before returning its attention to a message under transmission. However, for the configurations

and traffic anticipated for the combined Level I and FSAS, such a situation is not expected to occur. If, for future configurations and traffic, the situation becomes more likely, then a combination of the basic discipline and "fairness" approach may be required. Such a combination may be achieved by simply limiting the round-robin to a parametrically set number n of active ports. That is, bring a new message into the round robin transmission whenever the number of messages in the round robin drops below n.

The impact of the FSAS file transfer traffic is events of long delay. If these events are to be avoided, the queueing procedure employed at the switch must be such to disallow monopolizing of the switch-to-concentrator circuit by such traffic (or else the configuration must be changed). An n-limited round robin discipline is one such procedure. Because the value of n to ensure concentrator message output transmission continuity is expected to be large in comparison to the number of ports with messages in queue with NADIN I and FSAS traffic, the performance of the discipline can be reasonably approximated by an unlimited round-robin model. The appropriateness of this approximation can be readily determined from the results of its application. If the analysis shows end-to-end delays for message transfers over the concentrator-to-switch circuit of greater duration than their nominal transmission time over the concentrator output circuit, then the parameter n must be considered.

This modified switch discipline is preferrable to ad-hoc measures which prevent the file messages from monopolizing circuits, like special flagging and treatment of FSAS files. The more general approach of changing the switch discipline is preferred since NADIN is expected to grow and accommodate other users which will also have computer to computer transfers of large files. Also, considering the developmental stage of NADIN, a change of switch discipline is inexpensive because it can still be done in the design phase and does not require costly hardware. Line speeds of 4.8 and 9.6 Kbits/sec between switches and concentrators are taken as alternatives because a preliminary analysis showed them to satisfy NADIN delay requirements.

MITRE Contingency Plan: The MITRE corporation has proposed a contingency solution for FSAS communications in case the NADIN schedule slips. That solution is taken as the basis for the evaluation of the cost penalty of NADIN not supporting FSAS communications. Figure 4.2 shows the proposed connections of FSAS nodes:

- a dedicated 9.6 Kbits/sec line between each AWP and each FSDPS,

- two dedicated 9.6 Kbits/sec lines between the AWP's,

- multipoint 2.4 Kbits/sec lines between the WMSC and the FSDPSs with a maximum of 3 FSDPSs on each line.

Using these constraints and NAC's network design software tools, the configuration of FSDPSs on the multipoint lines which minimizes cost was obtained (Figure 4.3).

4.3 PERFORMANCE ANALYSIS MODELING

The modeling and analysis of NADIN yields the delays of messages given: FSAS traffic statistics, initial NADIN traffic statistics and NADIN configuration and operation (Appendices C, D and H). The raw traffic statistics are processed by adding protocol overhead, changing message statistics into frame statistics, and amalgamating several service time distributions into a single Gaussian distribution (Appendix K). Then, queueing delays are obtained on each of NADIN's backbone and interface links, using appropriate queueing models for each link. The average message delays are added to obtain overall network delays. The three types of messages considered are: 1) a NADIN message going between two concentrators connected to different switching centers, 2) an FSAS unscheduled weather report going from an AWP to an FSDPS and 3) a flight plan going from an FSDPS to an ARTCC. The cases considered in the analysis are: 1) basic M/G/1 model for all links when there are no file transfers, 2) special queueing model consisting of several simultaneous M/G/1 queues for the switch to concentrator links at times of file transfers. The 90th percentile delays and buffer occupancy are also calculated for each link and their aggregate values for several links are obtained using the methods developed in Appendix I.

The definition of seven generic links in the NADIN model is given in Appendix L. The solution of the switch to concentrator line model is given in Appendix M. The analysis of the buildup of a backlog of frames at the NADIN switch at times of file transfers is given in Appendix N and the probability of interframe delays is given in Appendix P.

The results of analysis are given graphically and numerically. Figures 4.3 to 4.12 show the delays of messages on NADIN backbone links. Tables 4.2 to 4.11 give in detail the values of delays and buffer occupancies. Appendix O illustrates by means of examples how the figures in Tables 4.1 to 4.10 are obtained.

4.4 FSAS/NADIN INTERFACE MODELING

The object of FSAS/NADIN interface modeling is to determine the necessary line speeds between AWPs and NADIN switches and between FSDPSs and NADIN concentrators and to determine what is needed to make the software interfaces of NADIN and FSAS compatible.

Line Speeds: The NADIN and FSAS nodes are colocated and will be using the EIA-RS-449 standard as an electrical interface. This standard allows high data rates (transmission of the order of 100 Kbits/sec) without use of modems. The rate of data exchange between NADIN and FSAS is, therefore, more limited by their ports speeds than by the lines. In view of this, a simple analysis was made to determine minimum interface line speeds needed (Referemce 29)/ The results are a minimum line speed of 4.8 Kbits/sec between FSDPS and NADIN concentrator and 9.6 Kbits/sec between AWP and NADIN switch. An AWP requires a higher speed because the switch to AWP link may carry the same weather data twice: unprocessed weather data from the WMSC and the same processed data coming from the other AWP.

Software Compatibility: The NADIN link level and message level data structure is examined in Appendix J in detail. It appears that the FSAS is entirely compatible with NADIN at the link level. At the message level, the FSAS program must make a choice of the NADIN capabilities applicable to FSAS traffic and decide jointly with the NADIN program how to code these capabilities in the message heading.

4.5 COST ANALYSIS MODELING

All recurring and fixed cost components of each alternative were determined, concatenated, and reduced to present value for comparison purpose. The following appendices present the costing methodology and detailed calculations:

- Appendix Q considers fixed and recurring costs of NADIN communications alternatives.

- Appendix R considers fixed & recurring costs of the leased line alternative.

- Appendix S considers present value calculations of NADIN and non-NADIN communications alternatives.

Cost components requiring no explanation that are used to assess alternatives in Appendices Q and R common to all alternatives are shown on Table Q.4. Other costs requiring explanation are surfaced in their respective appendices.

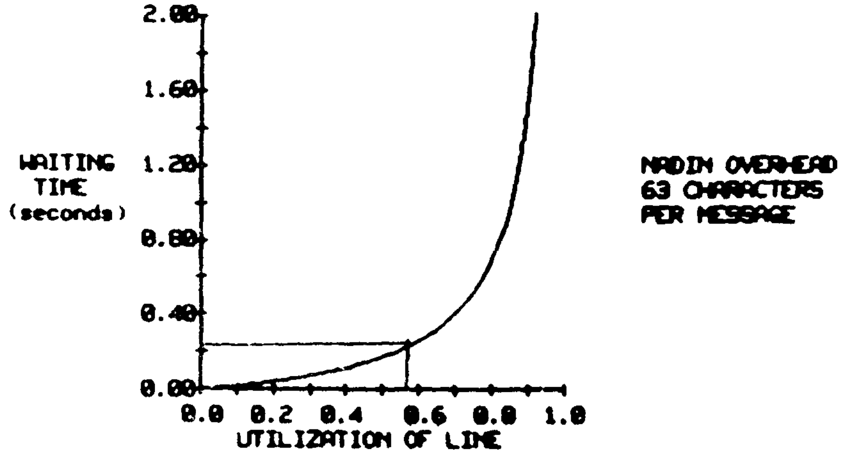


FIGURE 4.2: DELAYS ON SWITCH TO CONCENTRATOR LINE (4.8 Kb/s)

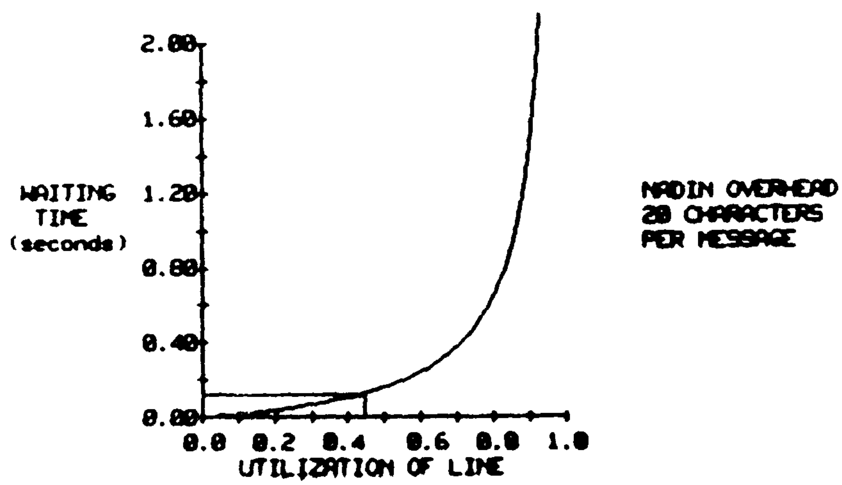


FIGURE 4.3: DELAYS ON SWITCH TO CONCENTRATOR LINE (4.8 Kb/s)

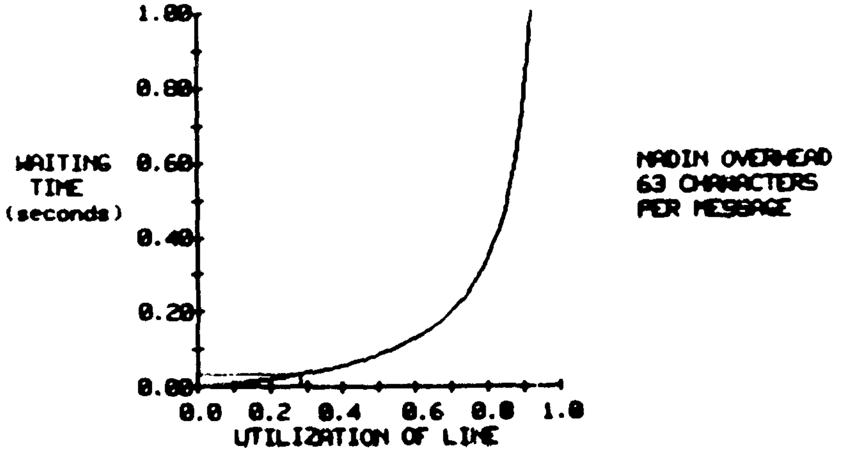


FIGURE 4.4: DELAYS ON SWITCH TO CONCENTRATOR LINE (9.6 Kb/s)

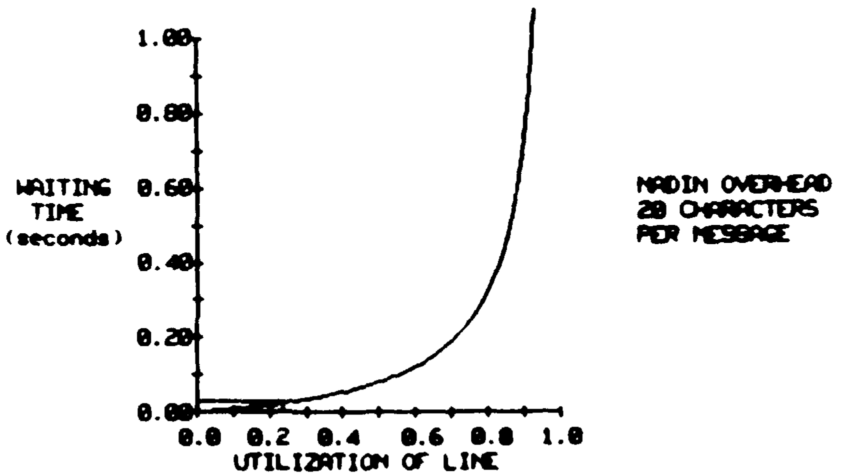


FIGURE 4.5: DELAYS ON SWITCH TO CONCENTRATOR LINE (9.6 Kb/s)

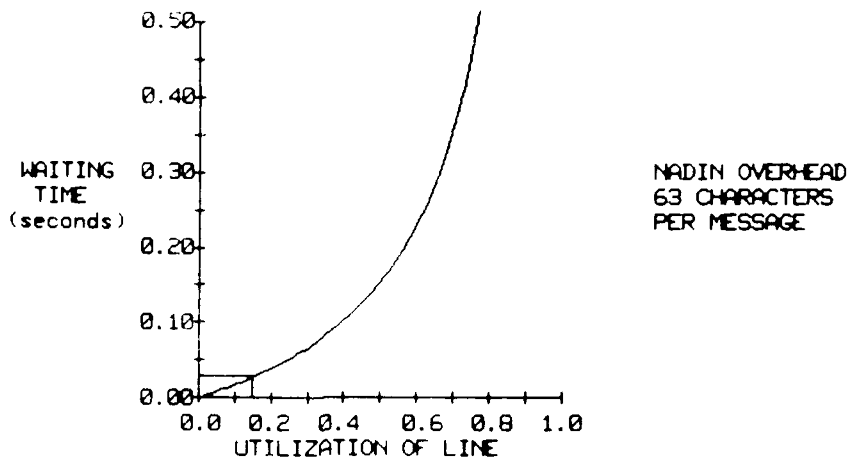


FIGURE 4.6: DELAYS ON CONCENTRATOR TO SWITCH LINE (4.8 Kb/s)

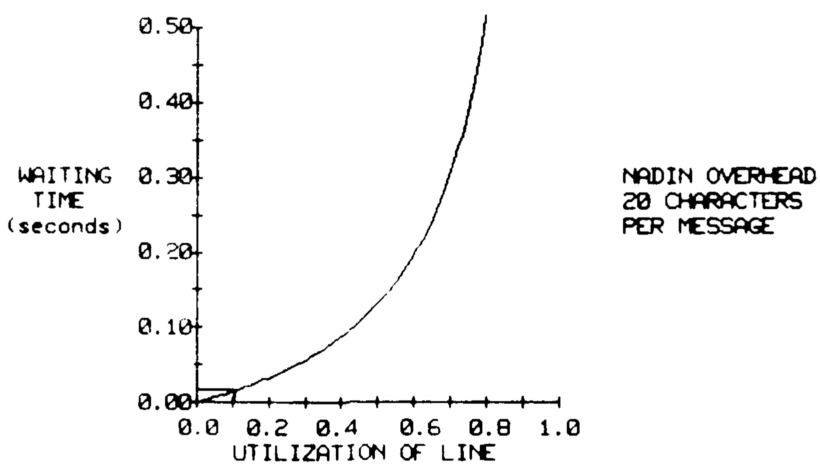


FIGURE 4.7: DELAYS ON CONCENTRATOR TO SWITCH LINE (4.8 Kb/s)

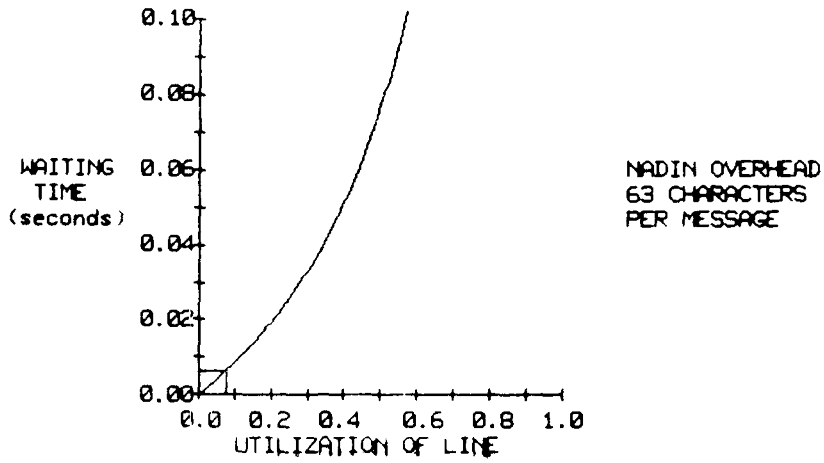


FIGURE 4.8: DELAYS ON CONCENTRATOR TO SWITCH LINE (9.6 Kb/s)

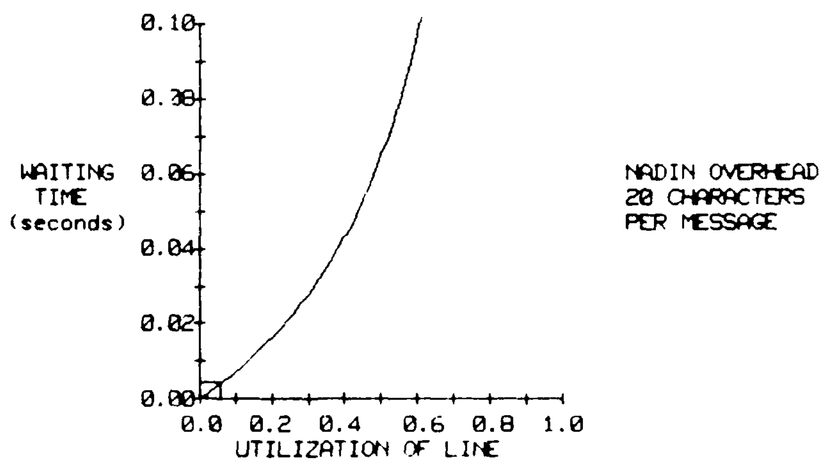


FIGURE 4.9: DELAYS ON CONCENTRATOR TO SWITCH LINE (9.6 Kb/s)

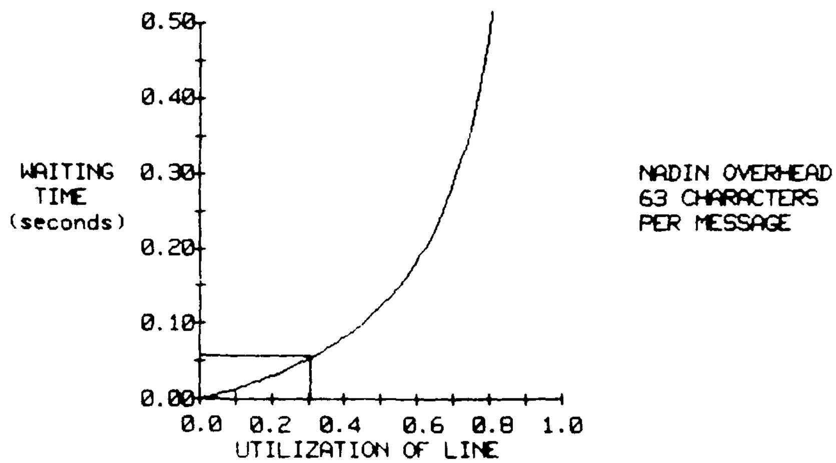


FIGURE 4.10: DELAYS ON SWITCH TO SWITCH LINE (9.6 Kb/s)

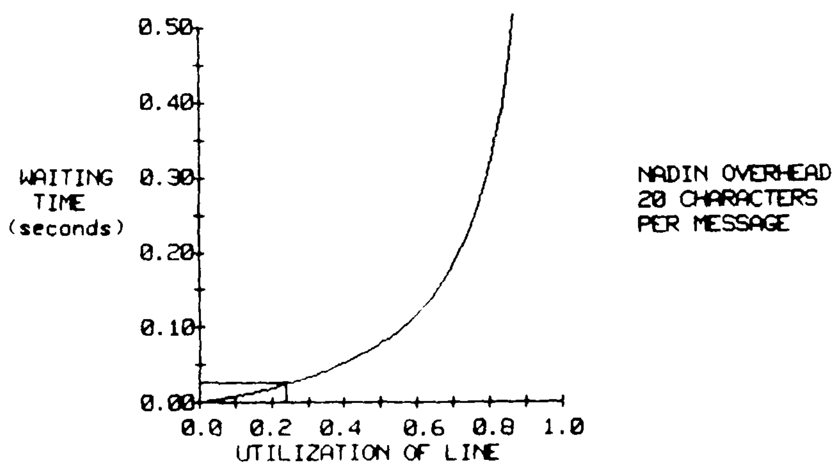


FIGURE 4.11: DELAYS ON SWITCH TO SWITCH LINE (9.6 Kb/s)

Line Speed (Switch to Concentrator)	NADIN Overhead (characters)	Total Delay (sec)	90th Percentile Delays (seconds)	Transmission Time (seconds)	Waiting Time (seconds)
4.8	63	1.141	1.974	0.859	0.282
4.8	20	0.872	1.480	0.710	0.162
9.6	63	0.593	0.920	0.515	0.078
9.6	20	0.477	0.837	0.426	0.051

TABLE 4.2: DELAYS OF NADIN I MESSAGES AND FLIGHT PLANS FROM FSDPS TO ARTCC BETWEEN PERIODS OF AWP FILE TRANSFERS (Concentrator-to-switch-to-switch-to-concentrator)

Line Speed Switch to Concentrator (Kbps)	NADIN Overhead (characters)	Total Delay (seconds)	90th Percentile Total Delay (seconds)	Transmission Time (seconds)	Waiting Time (seconds)	90th Percentile Waiting Delay (seconds)
4.8	63	0.964	1.821	0.711	0.253	1.110
4.8	20	0.636	1.267	0.493	0.143	0.774
9.6	63	0.523	0.868	0.474	0.049	0.394
9.6	20	0.360	0.646	0.328	0.032	0.318

TABLE 4.3: DELAYS OF FLIGHT PLANS FROM FSDPS TO FSDPS, BETWEEN PERIODS OF FILE TRANSFERS

Line Speed Switch to Concentrator (Kbps)	NADIN Overhead (characters)	Total Delay (seconds)	90th Percentile Total Delay (seconds)	Transmission Time (seconds)	Waiting Time (seconds)	90th Percentile Waiting Delay (seconds)
4.8	63	1.143	2.034	0.782	0.361	1.252
4.8	20	0.904	1.586	0.688	0.216	0.898
9.6	63	0.803	1.415	0.625	0.178	0.790
9.6	20	0.666	1.167	0.550	0.116	0.617

TABLE 4.4: DELAYS OF UNSCHEDULED MESSAGES FROM AWP TO FSDPS, BETWEEN PERIODS OF FILE TRANSFERS

Type of Node	Line Speed Switch to Concentrator	NADIN Overhead	Buffer size (Kbytes)
SWITCH	4.8	63	5.12
	4.8	20	3.50
	9.6	63	2.64
	9.6	20	2.14
CONCENTRATOR	4.8	63	1.35
	4.8	20	0.94
	9.6	63	0.38
	9.6	20	0.31

TABLE 4.5: BUFFER SIZE NEEDED AT SWITCHES AND CONCENTRATORS FOR 95% PROBABILITY OF NON-OVERFLOW

								AVERAGE LENGTH [illegible] FRAMES					
4.8	63	SA H+03	1097	1.257	1.501	0.257	1.137	1.873	0.090	2.613	0.429	786	502
4.8	20	SA H+03	1040	1.132	1.321	0.257	0.788	1.834	0.074	2.057	0.413	688	379
4.8	63	WA H+00	841	1.257	1.501	0.257	1.137	1.873	0.090	2.613	0.429	603	385
4.8	20	WA H+00	795	1.132	1.321	0.257	0.788	1.834	0.074	2.057	0.413	529	291
9.6	63	SA H+03	1097	1.257	1.501	0.257	1.137	1.873	0.045	2.613	0.204	103	157
9.6	20	SA H+03	1040	1.132	1.321	0.257	0.788	1.834	0.097	2.057	0.198	72	138
9.6	63	WA H+00	841	1.257	1.501	0.257	1.137	1.873	0.045	2.613	0.204	79	120
9.6	20	WA H+00	799	1.132	1.321	0.257	0.788	1.834	0.037	2.057	0.198	55	106

TABLE 4.6: SWITCH CYCLE TIME AND BUFFER OCCUPANCY AT TIMES OF FILE TRANSFERS

Line Speed Switch to Concentrator (Kbps)	NADIN Overhead (Characters)	Total Delay (Seconds)	Transmission Time (Seconds)	Waiting Time (Seconds)
4.8	63	4.498	0.709	3.789
4.8	20	4.196	0.566	3.630
9.6	63	2.198	0.432	1.766
9.6	20	2.077	0.348	1.724

TABLE 4.7: DELAYS OF NADIN I MESSAGES
(Concentrator-to-Switch-to-Switch-to-Concentrator)
During periods of file transfers. Unmodified Switch Operation.

Line Speed Switch to Concentrator (Kbps)	NADIN Overhead (Characters)	Total Delay (Seconds)	Transmission Time (Seconds)	Waiting Time (Seconds)
4.8	63	1.247	0.859	0.388
4.8	20	1.06	0.710	0.350
9.6	63	0.713	0.515	0.198
9.6	20	0.604	0.426	0.178

TABLE 4.8: DELAYS OF NADIN I MESSAGES (Concentrator-to-Switch-to-switch-to-concentrator) during periods of file transfers. MODIFIED SWITCH OPERATION.

Line Speed Switch to Concentrator (Kbps)	NADIN Overhead (Characters)	Total Delay (Seconds)	Transmission Time (Seconds)	Waiting Time (Seconds)
4.8	63	5.714	0.711	5.003
4.8	20	5.137	0.493	4.644
9.6	63	2.585	0.474	2.111
9.6	20	2.347	0.328	2.019

TABLE 4.9: DELAYS OF FLIGHT PLANS FROM FSDPS TO FSDPS, DURING PERIODS OF FILE TRANSFERS

Line Speed Switch to Concentrator (Kbps)	NADIN Overhead (Characters)	Total Delay (Seconds)	Transmission Time (Seconds)	Waiting Time (Seconds)
4.8	63	5.871	0.782	5.089
4.8	20	5.389	0.688	4.701
9.6	63	2.843	0.625	2.218
9.6	20	2.637	0.550	2.087

TABLE 4.10: DELAYS OF UNSCHEDULED MESSAGES FROM AWP TO FSDPS, DURING FILE TRANSFERS

CHAPTER 5

CONCLUSION

The FSAS program will be the major user of NADIN with a traffic throughput four times larger than the initial NADIN traffic. The introduction of FSAS data communications into NADIN raises the questions of technical adequacy of NADIN, cost effectiveness, and interface compatibility. This study addressed these questions and resulted in the following conclusions and recommendations.

5.1 TECHNICAL ADEQUACY OF NADIN

With minor enhancements, NADIN has been shown to be a sufficient communications utility for FSAS in terms of performance and compatibility.

If a line speed of 4.8 Kbits/sec between switches and concentrators is retained, the NADIN switch specification should be modified. Although a line speed of 4.8 Kbits/sec would satisfy the NADIN delay requirements, it is preferrable to upgrade the line to 9.6 Kbits/sec to improve performance and to have spare transmission capacity.

If the switch queueing output procedure is such that the switch to concentrator links can be monopolized by FSAS file messages for 16 continguous frames the line speeds between switches and concentrators must be upgraded to 19.2 Kbits/sec.

The change of queueing procedure is preferrable to the increase of line speeds to 19.2 Kbits/sec because it is a more fundamental solution to the problem of coexistence of interactive messages and large files in the same network, and because other future users of NADIN may, like FSAS, have large file transfers (e.g., Computer B to Computer B).

5.2 COST EFFECTIVENESS

The recommended alternative (NADIN use with trunk upgrade to 9600 bps) is over seven times more cost effective than a leased line approach. This is based upon three year present worth values of $288,314 and $2,134,808, respectively. Additionally, use of NADIN with 19.2 Kbits/sec trunk capacities is over three times more cost effective than a leased line approach. This based upon three year present value of $965,132 and $2,134,808, respectively.

5.3 FSAS-NADIN INTERFACE

While the FSAS and NADIN are basically compatible, some details of interface implementation have to be jointly finalized by the FSAS and NADIN implementation teams.

The line speeds between AWPs and NADIN switches, and between FSDPSs and NADIN concentrator, have to be a minimum of 9.6 and 4.8 Kbits/sec, respectively. However, these are local (hardwired), interfaces and higher speeds are readily accommodated on the RS-449 interface. It is suggested that the NADIN program can provide upper limits on the speeds of NADIN ports and then leave the final choice of hardware connections and line speed to the FSAS contractor.

The link protocol used in both FSAS and NADIN is the balanced version of ADCCP. The two networks are thus totally compatible at the link level of interface.

At the message level, the FSAS specification acknowledges the use of NADIN's message structure. There is a further need to:

- define the headings FSAS data needs in a NADIN message.
- define which program's responsibility it is to format messages.

Finally, buffer use at the NADIN switches was computed. It was shown that at the times of transmission of Surface Observations and Winds Aloft files there may be an accumulation of 100 to 200 Kbytes of frames waiting for transmission at the switches. This accumulation can be prevented by allowing NADIN to control the flow of files coming from the AWP. Such a flow control can be implemented via the use of NADIN control messages. While flow control is not an absolute necessity, because NADIN switches can store large files, it is desirable that NADIN have this option from the start. Flow control will make it easier for the future NADIN to accommodate and manage multiple users. Flow control should therefore be considered as a possibility and addressed by the FSAS and NADIN implementation programs.

APPENDIX A

SURVEY OF FSAS COMMUNICATIONS

The FSAS is an automation program which will improve the quality and efficiency of the services provided by Flight Service Stations (FSS). The program introduces new data processing capabilities and has new data communications needs. This section presents the FSAS concept and the FSAS data communication needs. It first describes the existing system and then discusses the planned automated system.

A.1 EXISTING SYSTEM

The FSSs provides weather and aeronautical briefings to pilots, receives flight plans, collects weather and aeronautical reports (PIREPS, Notams), and collects weather observations (Surface Observations). In other words, an FSS has the dual responsibility to collect and disseminate both weather and flight data. There are approximately 327 FSSs in the United States and they are connected to several data communications networks.

Generally speaking, weather data is transmitted over the Service A networks and flight data over the Service B networks. Service A and B networks consist of 75 baud teletypewriter multipoint circuits controlled by switches located in Kansas City, MO. The switches are the Weather Message Switching Center (WMSC) and the Automated B Data Interchange System (A-BDIS), respectively.

Due to its function, an FSS communicates with almost all types of FAA facilities. This includes:

- other FSSs, for the exchange of Visual Flight Rule (VFR) plans and Notams;
- Air Routing Traffic Control Centers (ARTCC), for filing IFR plans;
- Air Traffic Control System Command Center (ATCSCC) for flow control messages.

The specialists manually retrieve weather information to give briefings to pilots. This is time-consuming and, in busy stations, results in long service waiting times. The present use of functionally-limited teletypewriters does not permit enhanced services such as weather graphics. And, because of the low-speed local multipoint lines to which FSSs are connected, only a limited portion of the total national weathe. data is routinely available to an individual FSS.

A.2 AUTOMATED SYSTEM

The automated system will consolidate the functions of the FSS system at three levels: national, regional (ARTCC regions), and local (See Figure A.1). At the national level, there will be two Aviation Weather Processors (AWP) which receive and format all weather information. The AWPs share this activity in a dynamic way, and each of them maintains a national weather data base at all times which they relay to the FSDPSs. AWPs primarily handle weather data, but they also receive flow control messages from the ATCSCC and Notams from the NFDC.

At the regional level, colocated with each of 23 ARTCCs, there will be a Flight Service Data Processing System (FSDPS). Each FSDPS maintains a national weather data base and has the ability to retrieve weather information on a given flight route. The FSDPS relays IFR flight plans to ARTCC, and stores VFR plans for flights destined to airports within its boundaries.

At the local level, AFSSs will serve pilots (usually General Aviation pilots). The main input/output device is a console that interacts with an FSDPS in real time. Consoles are operated by specialists who in turn provide pilots with weather briefings and accept flight plans from the pilots. The AFSS makes radio contacts with aircraft and sends the aircraft's coordinates to the FSDPS. The AFSS also collects weather data and Notams, and sends the data to the FSDPS.

In addition to AFSSs, Direct User Access Devices (DUATs) permit a degree of decentralization. These devices are basically the same as consoles at the AFSS, but serve pilots directly without interaction with an FAA specialist. The DUATs communicate with the FSDPS, and are usually located at airports with sufficient activity to justify independent access to the FSDPS.

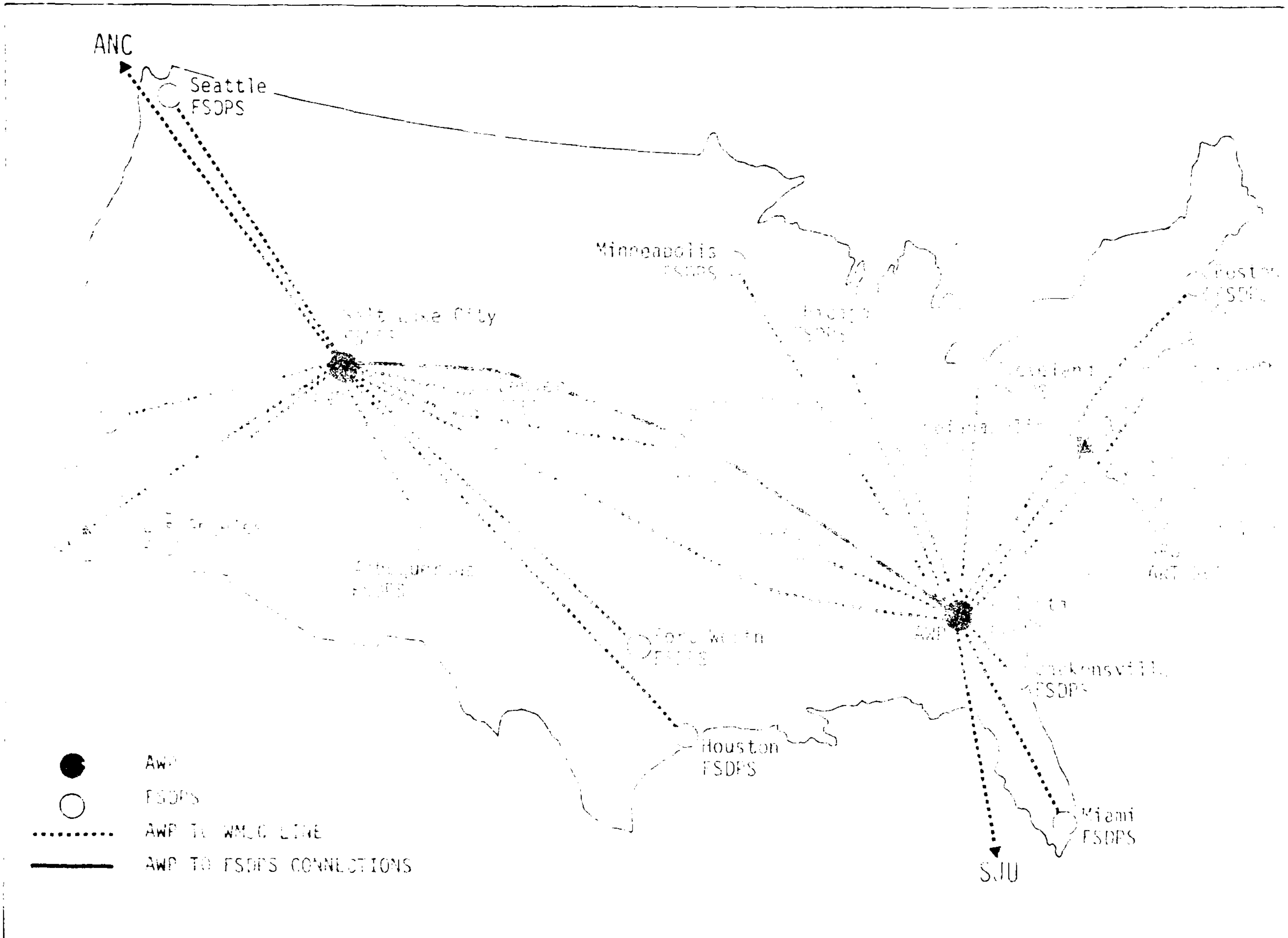


FIGURE A.1: AWP AND FSDPS FUNCTIONAL CONNECTIVITIES (FSDPS TO WMSC NOT SHOWN)

APPENDIX B

FSAS NODES AND CONNECTED SYSTEMS

This appendix describes the various FSAS components and connected systems (See Figure B.1). The description includes the function, location, implementation schedule, interface and performance of nodes. The Automated Flight Service Station locations and implementation schedules are in Appendix E.

The FSAS nodes described are the AWP, FDSPS, AFSS and DUAT. The connected systems are the WMSC, NFDC, NMC, ARTCC, ATCSCC, Wx and ARO.

<u>Aviation Weather Processor (AWP)</u>: An AWP receives, processes, stores, and distributes weather and aeronautical data to the FSDPSs. The sources of data are the WMSC (Weather), the FSDPSs (Notams, Surface Observations, Pilot Reports), NMC (AFOS weather graphics), the ATCSCC (flow control messages) and the CARF and NFDC (Notams). An AWP processes (i.e., formats and expands) the text of all the messages it receives (with the exception of CARF Notams, International Notams and flow control messages) and stores them until a new version is received. The two AWPs share this load dynamically and each sends the weather products it processes to the other. The AWPs will be located in Salt Lake City and Atlanta and are assumed to be in place in 1983 at the earliest.

The FSAS specification specifies the processing delays, availability and reliability of individual components. The overall system requirements are not given. The average AWP processing time of WMSC transmissions or FSDPS requests is 4 seconds. The overall system delay for AFOS graphics and weather radar data is about 100 seconds (Reference 2, Table 13A).

<u>Flight Service Data Processing System (FSDPS)</u>: The Flight Service Data Processing System (FSDPS) provides weather briefing information for specialists and pilots and processes and distributes flight data. Each FSDPS maintains a base of automated weather data.

The FSDPSs are part of Model II FSAS and will be installed in 1983 at the earliest. It is assumed that in 1983 (near term) there will be a maximum of 14 FSDPSs. These FSDPS are assumed located in the ARTCC regions containing the largest numbers of AFSSs. In the mid-term (1988), and long-term (2000), it is assumed that a maximum of 23 FSDPSs will be installed. Table B.1 gives the locations of FSDPSs, the time of implementation, the number of tributary AFSS, and the 6-digit area code and exchange at the locations.

The FSDPS is the central part of the FSAS and is therefore connected to all FSAS components: DUAT, AFSS, and AWP. In addition, the FSDPS will have connections to the WMSC, NFDC, ARTCC, Weather Radars, ARO, and ATCSCC. The nature of messages exchanged with each of these nodes are discussed in each node's summary and in Appendix C on FSAS traffic.

The FSDPS synchronous and asynchronous interfaces are listed in Table B.2. (Tables 2 and 3 of FSAS specifications Reference 2).

The FSDPS response times given in the FSAS specification are listed in Table B.3. These response times and the communications delays of various traffic classes add up to the total system delays.

Direct User Access Terminal (DUAT): The DUAT is an interactive data communications terminal connected to the FSDPS. The DUAT operator can display alphanumeric or graphic weather data and file flight plans to the FSDPS. The DUATs can be either user-owned or FAA-owned, and can operate in either synchronous or asynchronous mode.

Of the four types of DUATs, only the FAA-owned synchronous DUAT is of interest for communications design. Other types have to supply their own lines or use the public switched telephone network.

Weather Message Switching Center (WMSC): The WMSC, located in Kansas City, MO, is the central switch for FAA weather data communications network. The Service A multipoint circuits collect and disseminate weather data and terminate at the WMSC. When the Model II FSAS is installed and non-automated FSS are still in place, the WMSC will be responsible for the exchange of weather data between automated and

non-automated systems. The decommissioning of the WMSC is currently under consideration (Reference 18). Until such plans become firm, it is assumed that the WMSC remains.

National Flight Data Center (NFDC): The NFDC edits international and CARF Notams and passes them to the WMSC for dissemination. The NFDC also issues its own Notams. The editing and issuing of Notams is done in Washington, DC. All NFDC functions will later be consolidated at Atlanta. The FSAS will eventually get Notams directly from the NFDC via the AWP. It is assumed for now that Notams are routed through the WMSC.

National Meteorological Center (NMC): The NMC is part of the National Weather Service and is located in Suitland, MD. The NMC collects all weather data from the Automation of Field Operations Service (AFOS). AFOS data is partly alphanumeric, partly graphic. The AFOS graphics go directly to the AWPs and the AFOS alphanumeric data goes to the WMSC for retransmission to the AWPs and Service A multipoint circuits.

Air Route Traffic Control Center (ARTCC): The ARTCCs have control of the Instrument Flight Rule (IFR) flights. There are 23 ARTCC regions, 20 of which are in the contiguous U.S. Since the 23 FSDPS will be colocated with ARTCC's, and are to flight services what the ARTCCs are to air traffic control, it is assumed that the FSDPS boundaries coincide with ARTCC boundaries.

Air Traffic Control System Command Center (ATCSCC): The ATCSCC, located in Washington, DC, presently sends air traffic control messages to FSSs over Area B circuits. In the FSAS, these messages will go to the FSDPSs.

Airport Reservation Office (ARO): The ARO is colocated with the ATCSCC in Washington, DC and is responsible for the allocation of VFR flights in a few of the nation's busiest airports.

Weather Radars (Wx): Weather Radars provide digitized weather data to support the En Route Flight Assistance Service (EFAS). The Wx belong either to FAA or to NWS and will be connected to the FSDPS. The locations of Wx's are given in Map C-8 of DOD Flight Information Publication (Reference 19).

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NOV 80 DOT-FA79WA-4355
UNCLASSIFIED NAC/FR-303A/01 FAA-RD-80-128 NL

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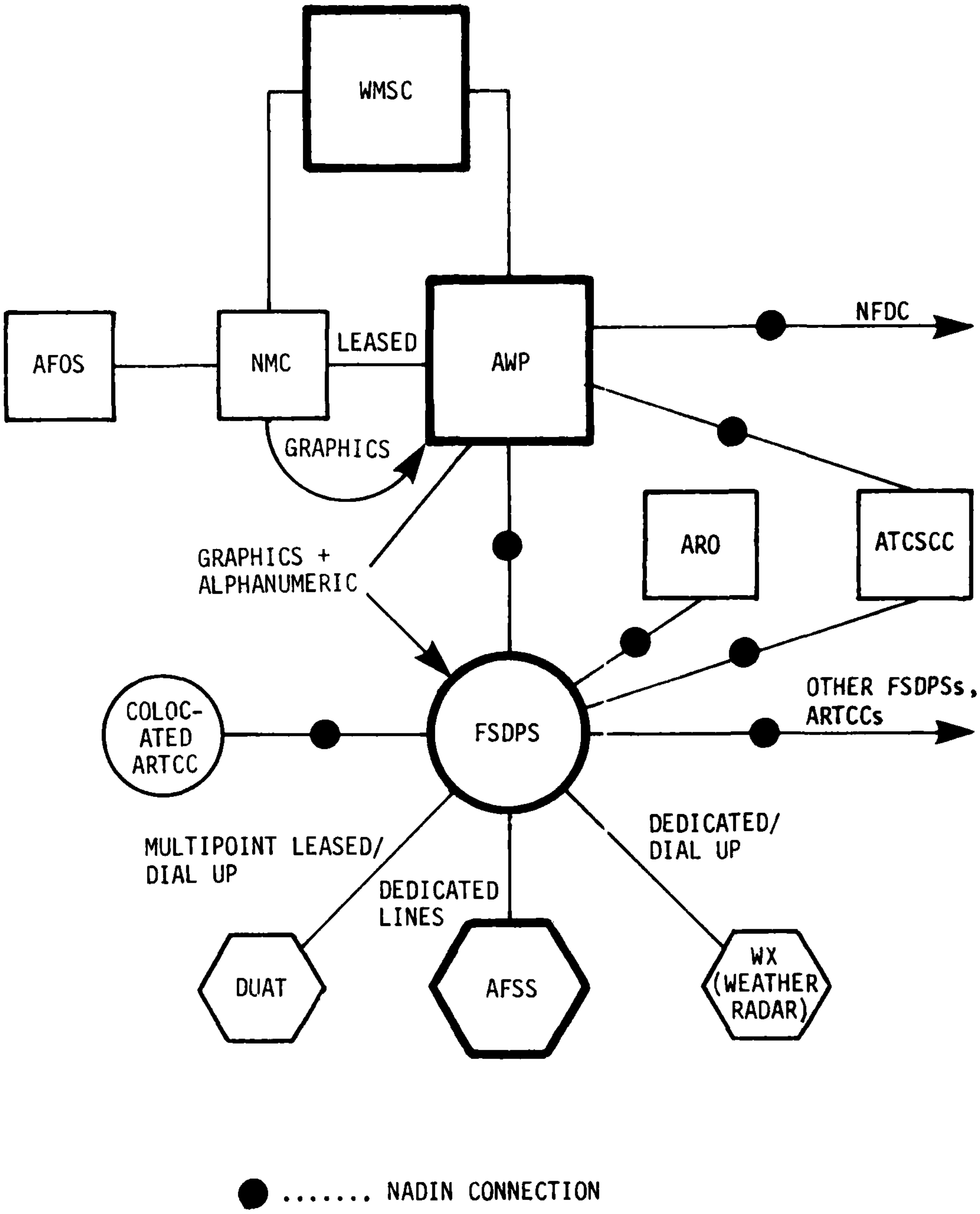


FIGURE B.1: FSAS INTERNAL AND EXTERNAL CONNECTIONS

CITY	nac IDENTI-FIER	STATE	IMPLE-MENTATION TIME NEAR TERM	MID TERM	AREA CODE AND EXCHANGE	NUMBER OF AFSS	AFSS IN SAME CITY
1. ALBUQUERQUE	ZAB	NM		X	505296	2	Y
2. ANCHORAGE	ZAN	AK	X		907333	3	Y
3. ATLANTA	ZTL	GA	X		404946	3	Y
4. BOSTON	ZBW	MA		X	603889	3	
5. CHICAGO	ZAU	IL	X		312897	2	Y
6. CLEVELAND	ZOB	OH	X		216774	4	Y
7. DENVER	ZDV	CO		X	303776	2	Y
8. FORT WORTH	ZFW	TX		X	817283	2	Y
9. HONOLULU	ZHL	HI		X	808734	1	Y
10. HOUSTON	ZHU	TX	X		713443	3	Y
11. INDIANAPOLIS	ZID	IN	X		317247	4	
12. JACKSONVILLE	ZJX	FL		X	904845	1	
13. KANSAS CITY	ZKC	MO	X		913782	3	Y
14. LOS ANGELES	ZLA	CA	X		213642	4	
15. MEMPHIS	ZME	TN	X		901365	4	Y
16. MIAMI	ZMA	FL	X		305592	2	Y
17. MINNEAPOLIS	ZMP	MN	X		612463	5	Y
18. NEW YORK	ZNY	NY	X		516737	3	
19. OAKLAND	ZOA	CA		X	415797	2	
20. SALT LAKE CITY	ZLC	UT	X		801521	3	Y
21. SAN JUAN	ZSJ	PR		X	809791	1	Y
22. SEATTLE	ZSE	WA		X	206833	2	Y
23. WASHINGTON	ZDC	DC	X		703777	3	Y

TABLE B.1: LOCATIONS OF FSDPS

COMMUNICATIONS CAPABILITY	SYNCHRONOUS	ASYNCHRONOUS
Line Type	Full Duplex	Full or Half-Duplex
Line Speed	2400,4800, or 9600 bps	1200 bps
Code	ASCII	ASCII
Error Control	CRC Check	Character Parity
Line Protocol	ADCCP	11-bit Start/Stop

TABLE B.2: FSDPS INTERFACE

RESPONSE TIME	MEAN (SEC)	90th PERCENTILE	99.5th PERCENTILE
To DUAT, AFSS	2	3.9	7.4
To Transmission From AWP for Storage in FSDPS Data Base	2	3.9	7.4
To Transmission From AWP or Remote Radar Site For Retransmission to AFSS	2	3.9	7.4
Key Echo (Asynchronous Only)	0.15	0.293	0.585
Key Echo (Others)	0.008	0.156	0.296

TABLE B.3: FSDPS RESPONSE TIMES

APPENDIX C

FSAS TRAFFIC STATISTICS

The bulk of FSAS traffic is weather data going from AWPs to FSDPSs and between AWPs. The FSDPSs also transmits unprocessed weather data to the AWPs and the WMSC, and transmits flight plans to other FSDPSs (VFR) and to ARTCCs (IFR). The traffic between FSAS computers and external systems does not, in general, appear on NADIN backbone links. For instance, the WMSC sends raw weather data over dedicated lines to the switches which retransmit it to the colocated AWPs. Since this study focuses on line delays and loading, excluding node delays and loading, the traffic between FSAS and external systems is documented here only in instances where it appears on NADIN backbone links.

The traffic statistics given here are always for a generic busiest connection. In instances where traffic is given in yearly figures, it is translated into hourly traffic by multiplying it by a factor of 0.00035. This is the factor used in the MITRE study documenting FSAS traffic requirements (Reference 16).

AWPS to FSDPS Traffic: The FSAS specification and the supporting MITRE's report document the AWP to FSDPS traffic (References 2, 16). The changes and additions made in the present report are based on the NFDC integration study (Notams), the FAA data communications handbook (Service A schedules), and oral communications from National Weather Service personnel (References 6, 14).

Tables C.1, C.2 and C.3 document the AWP to FSDPS traffic. Table C.1 lists scheduled AWP to FSDPS traffic which consists mainly of large file transfers. Table C.2 lists unscheduled AWP to FSDPS traffic and Table C.3 lists unscheduled urgent traffic. The distinction between scheduled and unscheduled traffic depends on the state of automation of Flight Service Stations. For instance, Surface Observations will eventually come from the FSDPSs more or less at random but at present they are collected by the WMSC and sent in bulk to the AWP. This study assumes bulk transmissions to ensure that recommended line speeds are adequate.

The following changes are made to the FSAS specification traffic table:

- The times of transmission of SA, FT, FA, TWEB route forecast and SD are either changed or included for the first time (WMSC schedules in Reference 6).
- All the parameters of all types of Notams are changed using figures from the NFDC integration study (Reference 14). Notam cancellation messages are included for the first time and their length is estimated to be 25 characters. There is one cancellation message for each Notam.
- The average number of messages for WH, WW, WO and AC are based on estimates provided by the Aviation Weather Branch of NWS. The number of AFOS graphics is changed from 36 to 86.

AWP to AWP Traffic: The AWPs exchange processed weather data. Since the sharing of processing is dynamic, an AWP may temporarily carry all or almost all the load and send as much data to the other AWP as it does to the FSDPSs. So, for conservative design, the AWP to the AWP traffic is assumed identical to AWP to FSDPS traffic.

FSDPS to AWP Traffic: The FSDPS to AWP traffic consists of Notams, Pireps and Surface Observations. If all the FSDPSs were installed, the average FSDPS traffic would be 1/23 (4.35%) of the total Notams, Pireps and Surface Observations going from AWP to FSDPS. It is assumed that the busiest FSPDS will send twice that average, i.e., approximately 10%. The messages marked with an asterisk in Tables C.1 to C.3 constitute the FSDPS to AWP traffic, after multiplication of the number of messages by 0.1. The FSDPS to WMSC traffic is identical to the FSDPS to AWP traffic.

FSDPS to FSDPS, ARTCC Traffic: FSDPS to FSDPS traffic consists of VFR flight plans and FSDPS to ARTCC traffic consists of IFR flight plans. All flight plans originate at AFSS controlled by the FSDPS. A VFR flight plan goes to the AFSSs which controls the destination airport. An IFR flight plan goes to the ARTCC which controls the departure airport. In addition, an ARTCC sends back acknowledgements for received IFR plans to the originating FSDPS.

It is assumed that 80 percent of VFR destinations are in the same FSDPS region and that 90 percent of IFR departure airports are within the same ARTCC region;

As a result:

- An FSDPS sends 20 percent of VFR flight plans to the nearest FSDPSs.
- An FSDPS sends 90 percent of IFR flight plans to the colocated ARTCC.
- An FSDPS sends 10 percent of IFR flight plans to the nearest adjacent ARTCCs.

It is also assumed that the busiest FSDPS will handle 10 percent of the national total of flight plans (as opposed to an average 4.3 percent per FSDPS) and that each FSDPS has 3 neighboring ARTCC regions.

The national totals of IFR and VFR plans for 1983, 1988, and 2000 are obtained from AVP forecasts in Reference 11 (the year 2000 figures are obtained by linear extrapolation).

	1983	1988	2000
IFR	9,701,086	12,403,364	18,888,831
VFR	3,198,656	3,403,639	3,895,598

With a peak hour to yearly traffic ratio of 0.00035, the number of messages per hour is:

	Near-term	Mid-term	Long-term
FSDPS to other FSDPS	7.5	7.9	9
FSDPS to colocated ARTCC	305.6	390.7	595
FSDPS to remote ARTCC	11.3	14.5	22

These numbers do not greatly differ from the figures given in Table 6 of the FSAS specification (Reference 2). That table completes the characterization of FSDPS to FSDPS and FSDPS to ARTCC traffic by giving the length of flight plans.

FSDPS to ARO, ATCSCC Traffic: An FSDPS and the ARO exchange messages concerning VFR flight plans which terminate at one of the busy airports having a limited number of VFR slots available. The FSDPS files the plan and the ARO either accepts, rejects, or delays it. The ATCSCC to FSDPS traffic consists of flow control messages. There is no traffic in the reverse direction. The FSDPS to ARO traffic is taken from Table 6 of the FSAS specification. The ATCSCC to FSDPS traffic is the 22nd entry in Table 5 of the FSAS specification.

	Mean Message Length (bits)	Messages/hour	Throughput (bits/sec)
FSDPS to ARO	320	7	0.62
ARO to FSDPS	120	7	0.23
ATCSCC to FSDPS	2000	5	2.78

ABBREVIATION	MESSAGE TYPE	MESSAGE LENGTH DISTRIBUTION	MEAN LENGTH (K BITS)	STANDARD DEVIATION BIAS (K BITS)	NUMBER OF REPORTS PER TRANSMISSION	TIME OF TRANSMISSION	FREQUENCY OF TRANSMISSION
1. SA	SURFACE OBSERVATION	NORMAL	0.72	0.13	1374	H+00	1/HR*
2. SA	MILITARY SURFACE OBSERVATION	NORMAL	0.72	0.13	168	H+25	1/HR
3. FT	TERMINAL FORECAST (expanded)	NORMAL	1.26	0.24	690	H+40	1/8 HR
4. FT	TERMINAL FORECAST (unexpanded)	FIXED	0.63	0.12	690	H+40	1/8 HR
5. FG	WINDS ALOFT	FIXED	760.00	--	1	H+00	1/12 HR
6. FA	AREA FORECAST (expanded)	NORMAL	19.2	2.4	11	H+40	1/12 HR
7. FA	AREA FORECAST (unexpanded)	NORMAL	9.6	1.2	11	H+40	1/12 HR
8. FX	PROGNOSTIC MAP DISCUSSION	NORMAL	16.	4.	1		2/DAY
9. TWEB	ROUTE FORECAST (expanded)	NORMAL	2.56	0.64	200	H+15 (MORNING, EVENING)	6/DAY
10. TWEB	ROUTE FORECAST (unexpanded)	NORMAL	1.28	0.32	200	H+15	6/DAY
11. TWEB	SYNOPSIS (expanded)	NORMAL	3.12	0.96	23	H+36	6/DAY
12. TWEB	SYNOPSIS (unexpanded)	NORMAL	1.56	0.48	23	H+36	6/DAY
13. SD	RADAR WEATHER REPORTS	NORMAL	1.12	0.12	136	H+56	1/HR

* SAME MESSAGE TYPE IN FSDPS TO AWP TRAFFIC

TABLE C.1: SCHEDULED MESSAGES FROM AWP TO FSDPS

[illegible]	MESSAGE TYPE	MESSAGE LENGTH DISTRIBUTION	MEAN (KBITS)	STANDARD DEVIATION OR BIAS (KBITS)	INTERARRIVAL TIME DISTRIBUTION	AVERAGE NUMBER OF MESSAGES/PEAK HOUR
[illegible]	DOMESTIC NOTAMS	BIASED EXP.	0.4		EXPONENTIAL	78*
2. [illegible]	INTERNATIONAL NOTAMS	BIASED EXP.	1.88		EXPONENTIAL	79*
[illegible]	CARF, NFDC NOTAMS	BIASED EXP.	1.8		EXPONENTIAL	4
[illegible]	NOTAMS CANCELLATION	BIASED EXP.	0.2		EXPONENTIAL	161
5. UA	PILOTS REPORTS (expanded)	NORMAL	1.44	0.24	EXPONENTIAL	430*
6. UA	PILOTS REPORTS (unexpanded)	NORMAL	0.72	0.12	EXPONENTIAL	430
7. WH	HURRICANE ADVISORY (expanded)	NORMAL	6.4	0.8	EXPONENTIAL	3
8. WH	HURRICANE ADVISORY (unexpanded)	NORMAL	3.2	0.4	EXPONENTIAL	3
9. WA	WEATHER WARNINGS	NORMAL	5.6	1.2	EXPONENTIAL	2
10. WO	TROPICAL DEPRESSION ADVISORY (expanded)	NORMAL	6.4	1.6	EXPONENTIAL	3
11. WO	TROPICAL DEPRESSION ADVISORY (unexpanded)	NORMAL	3.2	0.8	EXPONENTIAL	3
[illegible]	SEVERE WEATHER NARRATIVE	NORMAL	12.	3.2	EXPONENTIAL	1
13. WA	AIRMET (expanded)	NORMAL	1.95	0.24	EXPONENTIAL	5
14. WA	AIRMET (unexpanded)	NORMAL	0.98	0.12	EXPONENTIAL	5
[illegible] WS	SIGMET (expanded)	NORMAL	1.73	0.24	EXPONENTIAL	5
[illegible] WS	SIGMET (unexpanded)	NORMAL	0.86	0.12	EXPONENTIAL	5

* ONE MESSAGE TYPE IN FSDPS TO AWP TRAFFIC

TABLE C.2: UNSCHEDULED MESSAGES FROM AWP TO FSDPS (Continued)

ABBREVIATION	MESSAGE TYPE	MESSAGE LENGTH DISTRIBUTION	MEAN (KBITS)	STANDARD DEVIATION OR BIAS (KBITS)	INTERARRIVAL TIME DISTRIBUTION	AVERAGE NUMBER OF MESSAGES/PEAK HOUR
17. SP	SPECIAL OBSERVATION	NORMAL	0.72	0.13	EXPONENTIAL	165*
18. SW	SUPPLEMENTARY OBSERVATION	NORMAL	0.72	0.13	EXPONENTIAL	102*
19. FX	PROGNOSTIC MAP DISCUSSION	NORMAL	16.	4.	EXPONENTIAL	1
20.	AMENDMENTS	BIASED EXP.	2.69		EXPONENTIAL	107
21.	MISCELLANEOUS	NORMAL	0.4	0.12	EXPONENTIAL	25
22.	ATSCC MESSAGES	NORMAL	0.4	0.4	EXPONENTIAL	5
23.	MILITARY OPERATIONS	NORMAL	0.48	0.12	EXPONENTIAL	65
24.	AFOS GRAPHICS	NORMAL	32.	1.	EXPONENTIAL	86
25.	CONVECTIVE SIGMET	NORMAL	6.	2.	EXPONENTIAL	15

*SAME MESSAGE TYPE IN FSDPS TO AWP TRAFFIC

TABLE C.2: UNSCHEDULED MESSAGES FROM AWP TO FSDPS (Concluded)

ABBREVIATION	MESSAGE TYPE	MESSAGE LENGTH DISTRIBUTION	MEAN (KBITS)	STANDARD DEVIATION OR BIAS (KBITS)	INTERARRIVAL TIME DISTRIBUTION	AVERAGE NUMBER OF MESSAGES/PEAK HOUR
1. USP	URGENT SPECIAL SPECIAL OBSERVATION	NORMAL	0.72	0.13	EXPONENTIAL	5*
2. UUA	URGENT SPECIAL PILOT REPORT (expanded)	NORMAL	1.44	0.24	EXPONENTIAL	6*
3. UUA	URGENT SPECIAL PILOT REPORT (unexpanded)	NORMAL	0.72	0.12	EXPONENTIAL	6

* SAME MESSAGE TYPE IN FSDPS TO AWP TRAFFIC

TABLE C.3: URGENT MESSAGES FROM AWP TO FSDPS

APPENDIX D

NADIN DELAY REQUIREMENTS AND TRAFFIC

The initial NADIN traffic consists of Service B and AFTN traffic. The delay requirements are the maximum average and 90^{th} percentile delays to which messages are subjected in NADIN. Both traffic and delay requirements are given in Appendix Z of the NADIN specification (Reference 1).

The traffic statistics are given in Tables D.1 and D.2 in messages/hour. The message length statistics are given in Table D.3.

Three sets of delay requirements are given: 1) with normal traffic as in Tables D.1 and D.2; 2) with zero traffic (i.e., only transmission delays) and 3) with worst case, i.e., the traffic is 100% more than traffic in Tables D.1 and D.2. The requirements are:

Normal Traffic:

a) The average network delay of errorless format messages from concentrator B to concentrator E must be less than 2.0 seconds (see Figure D.1).

b) The average network delay T_N of errorless format messages of Level 1 priority from concentrator B to concentrator E must be less than 1.5 seconds.

c) Ninety percent of the errorless format messages from concentrator B to concentrator E must have a network delay T_N less than four seconds.

Zero Traffic:

a) With probability .5 or greater, the network delay T_N of an errorless format message from a concentrator served by Switch C to a concentrator served by Switch D is less than 1.2 seconds.

b) With probability .9 or greater, the network delay T_N of an errorless format message from a concentrator served by Switch C to a concentrator served by Switch D is less than 1.8 seconds.

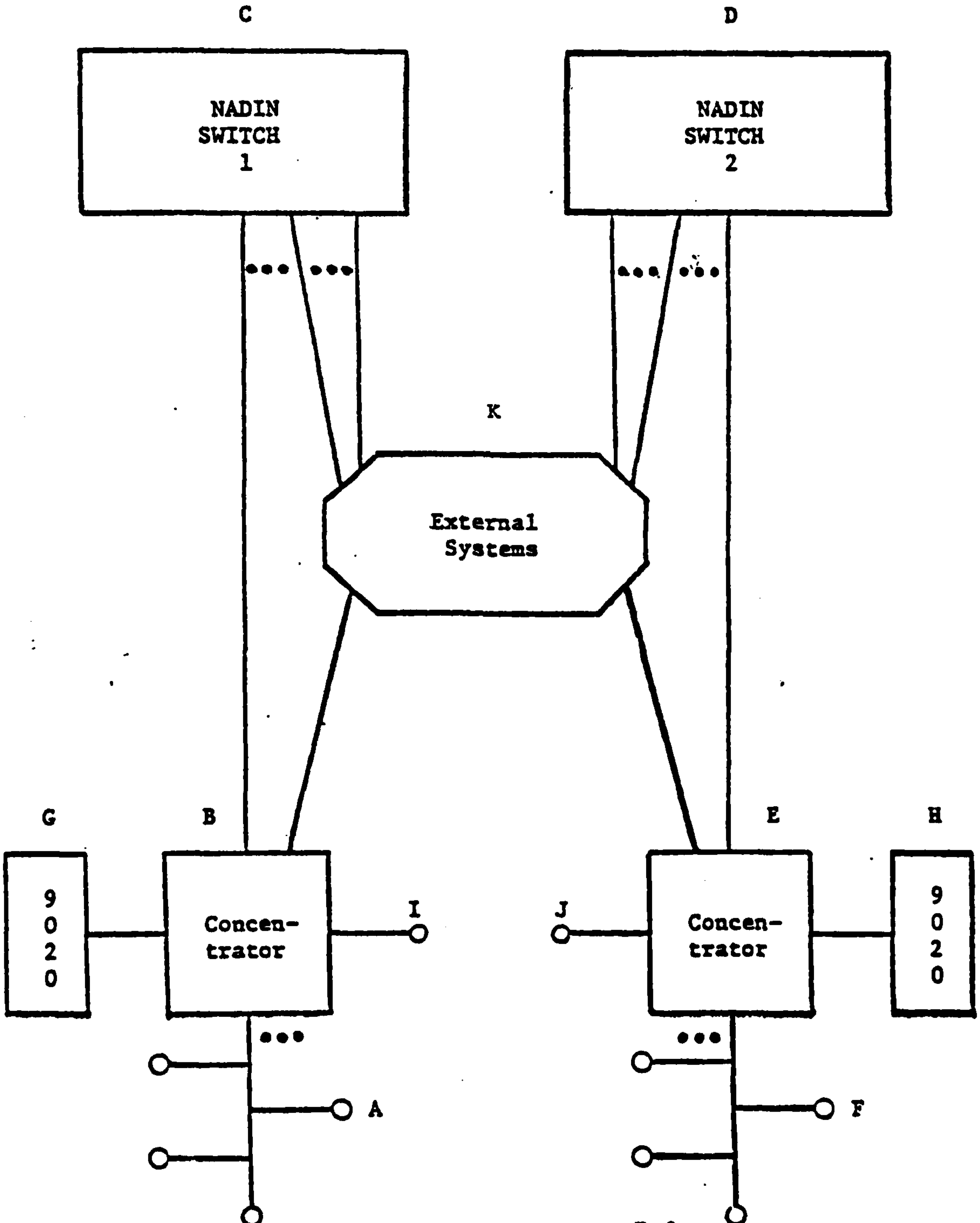
Worst Case:

a) The average network delay T_N of errorless format messages from concentrator B to concentrator E must be less than four seconds.

b) The average network delay T_N of errorless format messages of Level 1 priority from concentrator B to concentrator E must be less than 1.7 seconds.

c) Ninety percent of the errorless format messages from concentrator B to concentrator E must have a network delay T_N less than eight seconds.

FIGURE D-1 - FUNCTIONAL DIAGRAM OF NADIN ARCHITECTURE



			Input to Switch				Output From Switch			
ID	Port Type	No. of Lines	Message Type	Account?	MSG/HR Total	CPS Total	Message Type	Account?	MSG/HR Total	CPS Total
Concentrator	1	12	II II	Y N	8223 1080	275 36	II III II	Y N N	7998 168 1080	267 140 36
WMSC	14	1	II II III	Y N N	336 780 48	11 26 40	II II	Y N	336 780	11 26
Int'l AFTN	16	4	II	Y	240	8	II III	Y N	440 40	14 33
NWS	17	1	II III	Y N	440 160	14 133	II	Y	600	20
Switch	20	2	II II	Y N	2355 324	79 11	II II	Y N	2355 324	79 11
Dial-Up TTY	25	3	II	Y	120	4	II	Y	120	4
Airlines B	26	1	II	Y	150	5	II	Y	15	1
TOTAL				Y N	11864 2392	396 246		Y N	11864 2392	396 246

TABLE D.1: INITIAL NADIN SWITCH TRAFFIC

ID	Port Type	No. of Lines	Input to Concentrator				Output From Concentrator			
			Message Type	Account?	MSG/HR Total	CPS Total	Message Type	Account?	MSG/HR Total	CPS Total
Switch	1	1	II III II	Y N N	666 14 90	22 11 3	II II	Y N	685 90	23 3
9020	2	1	II II	Y N	301 30	10 1	II III II	Y N N	312 4 30	10 3 1
FOT	3	1	II	N	5	1	II	N	5	1
Local DTE	4	1	II II	Y N	8 2	1 1	II II	Y N	8 2	1 1
Remote DTE	5	2	II II	Y N	160 40	5 2	II II	Y N	160 40	5 2
Area B	6	4	II II	Y N	51 13	2 1	II II	Y N	51 13	2 1
Mil. B	7	1	II	Y	1	1	II	Y	1	1
AFTN	8	2	II	Y	60	2	II	Y	60	2
Air B & Util B	9	1	II	Y	14	1	II	Y	14	1
MAPS	10	1	II	Y	60	2	II	Y	60	2
INT'L AFTN	12	1	II	Y	30	1	III	N	10	8
TOTAL		16		Y N	1351 194	47 20		Y N	1351 194	47 20

TABLE D.2: INITIAL NADIN CONCENTRATOR TRAFFIC

Type	Message Length Distribution	Average Message Length	Spread	Minimum Length
I	Biased Exponential	50	——	25
II	Biased Exponential	120	——	60
III	Biased Exponential	3000	——	2000
IV	Uniform	90000	18000	——
V	Uniform	5	3	——
VI	Uniform	1600	100	——

TABLE D.3: MESSAGE TYPE CHARACTERISTICS

APPENDIX E

AFSS LOCATIONS AND TRAFFIC

Traffic data on the Automated Flight Service Stations (AFSS) was collected at an early stage of this study in order to analyse the impact of their data communications on NADIN. This analysis is now considered premature because AFSS to FSDPS connections will be through dedicated lines. The AFSS traffic data is nonetheless presented here because: 1) future FSAS plans may call for connections between AFSS and nodes other than the FSDPS, thus creating a need for NADIN, 2) the AFSS traffic data can be used as support information for the FSAS design of its internal communications.

AFSS Description: An AFSS consists of consoles operated by specialists who access the weather and aeronautical data base at the FSDPS. The specialists also contact aircraft and accept flight plans from pilots and file them with the FSDPS. The AFSS stores the most recent weather radar data and AFOS graphics.

An AFSS is connected only to the FSDPS of the ARTCC region to which it belongs. EIA-RS-449 Standard controls the electrical interface with the FSDPS, seven-bit ASCII code is used, and the link protocol is ADCCP.

AFSS Locations: The locations and numbers of AFSSs are not finalized yet. The general guidelines in predicting the AFSS locations are: 1) AFSSs should be evenly distributed among states, FAA regions and ARTCC areas of control, 2) AFSSs should be where the largest demand of general aviation users is expected. (There are of course other considerations like existing facilities and buildings, personnel training, etc.). The data on AFSS locations presented here does not aim to be an accurate picture of AFSS implementation but rather a "likely scenario" useful for any future preliminary study of AFSS communications. The two guidelines cited above (even geographical distribution and matching general aviation demand) are quantified, in conjunction with FSAS preliminary plans for automation, to construct such a scenario.

The FAA has established a tentative list of AFSS implementation (Reference 9). This list contains the locations of 61 AFSS. It was assumed that the locations which are at

airports already having a non-automated FSS will be the first to have an AFSS. This assumption results in Table E.1 which contains the locations of 61 AFSSs, 41 of which are to be implemented in 1983 at the earliest and 20 in 1988. The first 41 AFSSs are assumed connected to the 14 FSDPSs given in Table B.1. Table E.1 gives the name of each AFSS, its three letter identifier (or the identifier of the airport where it is located), the state, the expected implementation time (after 1983 or after 1988), the six digits of the area code and exchange and the FSDPS to which the AFSS will be attached. The time of implementation is calculated assuming that AFSSs in regions of largest demand are implemented first. The area code and exchange digits are inputs to NAC's network design software tool MIND and can be translated into Bell System V and H coordinates. The FSDPS to which an AFSS is connected is assumed to be the FSDPS colocated with the ARTCC which controls the airport where the AFSS is located.

AFSS Traffic: Tables E.2 and E.3 describe the AFSS-FSDPS traffic. Tables E.2A and E.2B list the various types of traffic (pilot briefs, aircraft contacts, etc.) and E.3 lists the ratio of traffic throughput at all 61 AFSSs to Miami's 1978 FSS traffic (baseline traffic). Miami's FSS is chosen because it had the largest traffic at the latest date for which figures were available (Reference 10).

The estimation of traffic for each AFSS in 1983, 1988 and 2000 is based on the preliminary forecasts of FSS activity by the Aviation Policy Office (Reference 12). This document lists the activity of all 327 FSSs. To determine the activity of the 61 AFSSs, it is assumed that the traffic of non-automated FSSs will gradually be diverted to the nearest AFSS, the traffic of the smallest FSSs being diverted first.

For example, the following steps are made to obtain the activity of the Birmingham, AL AFSS, controlled by the Atlanta FSDPS:

(1) For near-term, the activity is equal to the forecasted activity of non-automated FSS in Birmingham for 1983.

(2) In mid-term, the FSS traffic at Anderson SC, Tuscaloosa AL, and Bristol Tri City TN, is expected to be diverted to AFSSs. The sum of activity at these three stations is divided equally between the AFSS at Atlanta GA,

Greenville SC and Birmingham AL (the 3 AFSS controlled by the Atlanta FSDPS). This portion, added to the forecasted activity for 1988 at Birmingham FSS, gives the mid-term Birmingham AFSS traffic.

(3) In the long-term, all the FSS traffic in the Atlanta FSDPS region is diverted to AFSSs. The FSS projected traffic for 2000 is equally divided between the Atlanta, Greenville and Birmingham AFSSs. This is added to the 2000 forecast at Birmingham to give the total long-term Birmingham AFSS activity.

CITY	IDENTIFIER	STATE	IMPLEMENTATION TIME		AREA CODE AND EXCHANGE	FSDPS
			NEAR-TERM	MID-TERM		
Albuquerque	ABQ	NM		X	505243	Albuquerque
Mesa	MES	AZ		X		Albuquerque
Anchorage	MRI	AK	X		907272	Anchorage
Fairbanks	FAI	AK	X		907452	Anchorage
Juneau	JUN	AK	X		907586	Anchorage
Altanta	ATL	GA	X		404691	Atlanta
Birmingham	BHM	AL	X		205254	Atlanta
Greenville	GMU	SC		X	803233	Atlanta
Augusta	AUG	ME		X	207622	Boston
Bedford	BED	MA		X	617247	Boston
Burlington	BUR	VT		X	802862	Boston
Chicago	CHI	IL	X		312584	Chicago
Milwaukee	MKE	WI	X		414747	Chicago
Buffalo	BUF	NY	X		716846	Cleveland
Cleveland	CLE	OH	X		216267	Cleveland
Pittsburg	AGC	PA	X		612462	Cleveland
Pontiac	PTK	MI		X	31366	Cleveland
Denver	DEN	CO		X	303837	Denver
Casper	CPR	WY		X	307235	Denver
Oklahoma City	OKC	OK		X	405787	Fort Worth
Fort Worth	FTW	TX		X	817624	Fort Worth
Honolulu	HNL	HI		X	808845	Honolulu
New Orleans	NEW	LA	X		504241	Houston
Houston Hobby	HOU	TX	X		713644	Houston
San Antonio	SAN	TX	X		512826	Houston
Lafayette	LAF	IN	X		317743	Indianapolis
Louisville	LOU	KY	X		502451	Indianapolis

TABLE E.1: LOCATIONS OF AFSS.

CITY	IDENTIFIER	STATE	IMPLEMENTATION TIME		AREA CODE AND EXCHANGE	FSDPS
			NEAR-TERM	MID-TERM		
Columbus	CMH	OH	X		614237	Indianapolis
Charleston	CPW	WV	X		304343	Indianapolis
Tallahassee	TLH	FL		X	179188	Jacksonville
Wichita	ICT	KS	X		316267	Kansas City
Kansas City	MKG	MO	X		816471	Kansas City
St. Louis	STL	MO	X		314532	Kansas City
San Diego	SAN	CA	X		714291	Los Angeles
Las Vegas	LAS	NV	X		702385	Los Angeles
Riverside	RAL	CA		X	714687	Los Angeles
Van Nuys	VNY	CA		X	213785	Los Angeles
Little Rock	LIT	AR	X		501372	Memphis
Jackson	JAN	MS	X		601939	Memphis
Memphis	MEM	TN	X		901345	Memphis
Nashville	BNA	TN	X		615251	Memphis
Miami	MIA	FL	X		305233	Miami
Orlando	ORL	FL	X		305420	Miami
Des Moines	DSM	IA	X		515285	Minneapolis
Minneapolis	MSP	MN	X		612726	Minneapolis
Omaha	OMA	NE	X		402422	Minneapolis
Grand Forks	GFK	ND	X		701772	Minneapolis
Sioux Falls	FSD	SD		X	605338	Minneapolis
Teterboro	TEB	NJ	X		201288	New York
Islip MacArthur	ISP	NY	X		516737	New York
North Philadelphia	PNE	PA	X		215673	New York
Sacramento	SAC	CA		X	916440	Oakland
Hayward	HWD	CA		X	415783	Oakland
Boise	BOI	ID	X		208343	Salt Lake City

TABLE E.1: LOCATIONS OF AFSS.

CITY	IDENTIFIER	STATE	IMPLEMENTATION TIME		AREA CODE AND EXCHANGE	FSDPS
			NEAR-TERM	MID-TERM		
Billings	BIL	MT	X		406259	Salt Lake City
Salt Lake City	SLC	UT	X		801526	Salt Lake City
San Juan	SJU	PR		X	809791	San Juan
Portland	POX	OR		X	503648	Seattle
Seattle	SEA	WA		X	206767	Seattle
Chantilly	CHA	VA		X	703661	Washington
Raleigh	RDU	NC	X		919755	Washington
Washington	DCA	DC	X		703777	Washington

TABLE E.1: LOCATIONS OF AFSS.

TYPE OF MESSAGE	MESSAGE LENGTH DISTRIBUTION	MEAN MESSAGE LENGTH (KBITS)	MESSAGE COEFFICIENT (BIAS OR STANDARD DEVIATION)	INTERARRIVAL DISTRIBUTION	BASELINE THROUGHPUT (MESSAGES/HR)
1. FLIGHT PLAN	BIASED EXPONENTIAL	0.96	0.32	EXPONENTIAL	89.6
2. AIRCRAFT CONTACT	NORMAL	0.32	0.08	EXPONENTIAL	88.5
3. REQUEST FOR BRIEFING	NORMAL	0.2 ESTIMATE	0.05 ESTIMATE	EXPONENTIAL	140.1
4. NOTAM, PIREP, SA	NORMAL	0.8	0.16	EXPONENTIAL	34.3

TABLE E.2A: AFSS TO FSDPS TRAFFIC CLASSES

TYPE OF MESSAGE	MESSAGE LENGTH DISTRIBUTION	MEAN MESSAGE LENGTH (KBITS)	MESSAGE COEFFICIENT (BIAS OR STANDARD DEVIATION)	INTERARRIVAL DISTRIBUTION	BASELINE THROUGHPUT (MESSAGES/HR)
1. AFOS GRAPHICS	NORMAL	32	8	EXPONENTIAL	86
2. WEATHER RADAR	FIXED	453.6	--	EXPONENTIAL	26
3. ROUTE ORIENTED BRIEFING	NORMAL	40	12	EXPONENTIAL	93.4
4. LOCAL BRIEFING	NORMAL	12	4	EXPONENTIAL	46.7

TABLE E.2B: FSDPS TO AFSS TRAFFIC CLASSES

IDENTIFIER	PILOT BRIEFS			FLIGHT PLANS			AIRCRAFT CONTACTED		
	NEAR-TERM	MID-TERM	LONG-TERM	NEAR-TERM	MID-TERM	LONG-TERM	NEAR-TERM	MID-TERM	LONG-TERM
Albuquerque	0	0.354	1.586	0	0.235	1.175	0	0.310	0.794
Mesa	0	0.705	2.269	0	0.443	1.787	0	0.434	1.161
Anchorage	0.424	0.494	1.121	0.313	0.363	0.868	0.341	0.337	0.912
Fairbanks	0.183	0.232	0.809	0.249	0.297	0.799	0.267	0.270	0.860
Juneau	0.059	0.076	0.552	0.106	0.118	0.519	0.142	0.157	0.772
Altanta	0.753	1.070	2.772	0.643	0.844	1.893	0.265	0.300	0.512
Birminghan	0.305	0.542	2.029	0.258	0.397	1.277	0.139	0.175	0.392
Greenville	0	0.063	1.541	0	0.098	0.863	0	0.039	0.263
Augusta	0	0.231	1.547	0	0.185	1.534	0	0.275	0.445
Bedford	0	0.065	1.291	0	0.033	1.310	0	0.088	0.298
Burlington	0	0.065	1.291	0	0.033	4.643	0	0.088	0.298
Chicago	1.201	1.1778	4.947	0.867	1.399	3.278	0.634	0.921	1.823
Milwaukee	0.493	0.852	3.340	0.453	0.777	1.318	0.192	0.427	1.204
Buffalo	0.403	0.503	2.963	0.539	0.640	1.318	0.111	0.114	0.456
Cleveland	0.595	0.850	3.859	0.839	1.146	2.528	0.190	0.228	0.964
Pittsburg	0.461	0.575	3.076	0.411	0.506	1.176	0.156	0.155	0.487
Pontiac	0	1.044	4.127	0	1.089	2.512	0	0.379	1.021
Denver	0	1.035	2.023	0	0.663	1.244	0	0.494	0.815
Casper	0	0.219	0.791	0	0.126	0.494	0	0.228	0.602
Oklahoma City	0	0.618	3.081	0	0.355	2.338	0	0.358	0.817
Fort Worth	0	0.884	4.733	0	0.199	1.292	0	0.313	0.787
Honolulu	0	0.193	0.307	0	0.391	0.517	0	0.417	0.495
New Orleans	0.472	0.600	1.694	0.435	0.539	1.451	0.141	0.193	0.484
Houston Hobby	0.756	0.944	2.214	o.761	0.931	2.033	0.206	0.255	0.538
San Antonio	0.419	0.549	1.652	0.482	0.593	1.524	0.202	0.257	0.555
Lafayette	0.191	0.320	1.532	0.112	0.215	1.377	0.091	0.181	0.536
Louisville	0.317	0.439	1.618	0.228	0.315	1.399	0.099	0.173	0.686
Columbus	0.459	0.686	2.216	0.481	0.704	2.243	0.172	0.300	0.777

TABLE E.3: AFSS TRAFFIC (as a fraction of Miami's 1978 traffic)

IDENTIFIER	PILOT BRIEFS			FLIGHT PLANS			AIRCRAFT CONTACTED		
	NEAR-TERM	MID-TERM	LONG-TERM	NEAR-TERM	MID-TERM	LONG-TERM	NEAR-TERM	MID-TERM	LONG-TERM
Charleston	0.198	0.302	1.427	0.109	0.181	1.226	0.102	0.171	0.471
Tallahasee	0	0.414	3.215	0	0.296	3.039	0	0.116	1.006
Wichita	0.507	0.676	2,128	0.327	0.432	1.695	0.146	0.224	0.623
Kansas City	6.609	0.811	2.362	0.480	0.630	1.795	0.249	0.317	0.693
St. Louis	0.584	0.761	2.144	0.689	0.602	1.676	0.231	0.299	0.675
San Diego	0.440	0.572	1.464	0.391	0.515	1.194	0.234	0.249	0.639
Las Vegas	0.393	0.473	1.196	0.550	0.652	1.266	0.271	0.278	0.449
Riverside	0	0.648	1.628	0	0.303	1.237	0		
Van Nuys	0	1.444	2.958	0	0.882	2.103	0	0.550	0.701
Little Rock	0.353	0.467	1.977	0.279	0.363	1.071	0.126	0.161	0.351
Jackson	0.202	0.273	0.938	0.132	0.176	0.764	0.128	0.164	0.355
Memphis	0.404	0.510	1.275	0.440	0.531	1.248	0.199	0.236	0.428
Nashville	0.448	0.551	1.306	0.328	0.404	1.077	0.144	0.155	0.357
Miami	1.224	1.496	2.773	1.224	1.540	2.602	1.224	1.369	1.551
Orlando	0.484	0.684	1.771	0.353	0.563	1.341	0.208	0.342	0.505
Des Moines	0.288	0.381	1.368	0.204	0.270	1.077	0.080	0.118	1.060
Minneapolis	0.725	0.983	2.505	0.569	0.817	2.262	0.358	0.471	1.624
Omaha	0.392	0.511	1.573	0.355	0.446	1.321	0.168	0.198	1.123
Grand Forks	0.145	0.206	1.101	0.136	0.170	0.878	0.062	0.169	1.423
Sioux Falls	0	0.024	0.807	0	0.013	0.663	0	0.044	1.000
Teterboro	0.538	0.726	2.448	0.339	0.484	1.668	0.149	0.208	0.392
Islip	0.645	0.817	2.475	0.552	0.697	1.864	0.172	0.224	0.393
North Philadelphia	0.628	0.816	2.526	0.685	0.868	2.144	0.101	0.163	0.353
Sacramento	0	0.610	2.551	0	0.431	1.885	0	0.218	0.692
Hayward	0	1.282	3.729	0	0.983	2.897	0	0.544	0.967
Boise	0.197	0.283	1.021	0.185	0.265	0.854	0.133	0.188	0.526
Billings	0.135	0.184	0.943	0.081	0.116	0.556	0.100	0.156	0.495
Salt Lake City	0.360	0.458	1.360	0.275	0.341	0.868	0.266	0.306	0.609

TABLE E.3: AFSS TRAFFIC (as a fraction of Miami's 1978 traffic)

IDENTIFIER	PILOT BRIEFS			FLIGHT PLANS			AIRCRAFT CONTACTED		
	NEAR-TERM	MID-TERM	LONG-T	AR-TERM	MID-TERM	LONG-TERM	NEAR-TERM	MID-TERM	LONG-TERM
San Juan	0	0.200	0.500	0	0.6	1.000	0	0.8	0.8
Portland	0	0.935	2.875	0	0.750	2.661	0.000	0.368	0.813
Seattle	0	0.918	2.853	0	0.986	2.685	0	0.324	0.798
Chantilly	0	0.046	0.539	0	0.026	0.532	0	0.068	0.155
Raleigh	0.502	0.631	1.352	0.510	0.613	1.333	0.262	0.297	0.354
Washington	1.030	1.270	2.314	0.750	0.959	1.871	0.353	0.403	0.448

TABLE E.3: AFSS TRAFFIC(as a fraction of Miami's 1978 traffic)

APPENDIX F

MESSAGE PRIORITIES IN NADIN

Messages have four levels of internal priority at the switches and two levels of output link priority. In addition, network management messages have precedence for transmission over information messages of the same link priority. (NADIN specification, Paragraph 3.3.2.2.8). The correspondence between internal priorities, output priorities and the International Civil Aviation Organization (ICAO) (1) priorities is:

ICAO Priority	NADIN Switch Interval Priority	NADIN Output Link Priority
SS	1	1
DD	2	2
FF	3	2
GG	4	2
JJ	4	2
KK	4	2
LL	4	2

The ICAO also recommends (1) that messages with same priority be transmitted in the order in which they are received for transmission (i.e., on a first come first serve (FCFS) basis).

Appendix H describes in detail the relation between internal switch priorities and output link priorities. Internal priorities apply to messages processed inside the switch and output priorities apply to messages in a partial state of transmission and simultaneously outputted with other messages.

The FSAS specification has not assigned priorities to the various clases of messages. As a working assumption, the following assignment of priorities is suggested:

Priority 2: Flight related messages such as flight plans and flow control messages from the ATCSCC.

Priority 3: Weather related messages which are transmitted on an individual basis such as AFOS graphics as well as Pilot Reports and Surface Observations transmitted by automated flight service stations.

Priority 4: Large files of weather data coming from the WMSC and retransmitted by the AWP after processing. For example Winds Aloft and Surface Observations.

With this assignment, all FSAS messages have a link priority of two. The original NADIN traffic also has link priority of two, except for a very small percentage of priority one messages.

Priorities and Delays: - The effect of priorities on message delays is to diminish the delays of high priority messages at the expense of low priority messages while keeping the overall average delay the same. In NADIN, almost all messages have second link priority and therefore the average delay does not significantly differ from the delay of second priority messages.

APPENDIX G

EFFECTS OF THE FRAGMENTATION OF MESSAGES INTO ADCCP FRAMES

Messages which exceed the information length in an ADCCP frame in NADIN are transmitted as several frames. Breaking messages into frames affects the modeling of the transmission of messages as an M/G/1 queue in two ways. First, frame arrivals are no longer a Poisson process, since a long message creates a "cluster" of successive frames. Second, the length distribution of frames (or service time distribution) obviously differs from that of messages.

The change in arrival patterns probably has little effect because the assumption of Poisson arrivals is robust and usually predicts delays close to observed values (Reference 19). Therefore, the assumption of Poisson message arrivals is retained for frames.

The change of length distribution of messages when split into frames cannot be ignored since waiting times are directly proportional to message or frame lengths. Stated mathematically the problem is: given a message length probability density function (pdf) $p_X(x)$, and given a maximum frame length L, what is the pdf $p_Y(y)$ of frame length after messages are broken into frames? With the problem stated in these terms, a general relation between $p_Y(y)$ and $p_X(x)$ can be obtained , but it is quite complex and unwieldy. To obtain an approximate solution, the message length distribution is assumed exponential and the resulting frames are assumed to either have a length L or be uniformly distributed.

From the assumption on frame length distribution, $p_Y(y)$ is approximately given by:

$$p_Y(y) = \beta\delta(y-L) + \frac{(1-\beta)}{L} \qquad L_H \leq y \leq L$$

β is the expected portion of frames having the maximum length L

$\delta(y-L)$ is the unit impulse function which is zero except for y=L

L_H is the length of ADCCP header and trailer

$L' = L-L_H$ is the maximum length of information in a frame

The second term in the R.H.S. of the above equation approximates the length distribution of incomplete frames (last frame in messages). The length of the last frame of a message can have any length between L-L' and L with equal probability. This is a good approximation, especially when the average length of messages is large compared to the length L of a frame. Intuitively, the last frame of message having a smooth length distribution is equally likely to have any length between 0 and L'.

Assuming that messages have an exponential distribution somewhat simplifies the calculation of β which depends on the distribution $p_X(x)$, since it is difficult to obtain β in closed form for most distributions. It is also difficult to quantitatively assess the effect of this uniformity assumption on the pdf $p_Y(y)$. Intuitively, the functional form of $p_X(x)$ should not have too much effect on the average number of full frames per message.

The value of β is given in general by the following (exact) expression:

$$\beta = \sum_{n=0}^{\infty} \frac{n}{n+1} a_n \qquad (*)$$

where:

$$a_n = \text{Prob}\,(n\,L \leq X < (n+1)\,L)$$

$$= \int_{n\,L}^{(n+1)\,L} p_X(x)\,dx$$

This expression for β is obtained by averaging the fraction of full frames when X is between nL and (n+1)L, for all values of X. X is between nL and (n+1)L with probability a_n.

Equation (*) can be put in a somewhat simpler form as follows:

Let:

$$A_n = \int_{nL}^{\infty} p_X(x)\,dx$$

Clearly:

$$a_n = A_n - A_{n+1}$$

Substituting $A_n - A_{n+1}$ in Equation (*) gives, after some algebra:

$$\beta = \sum_{n=1}^{\infty} \frac{A_n}{n(n+1)}$$

Specializing now to the case of an exponential distribution of messages:

$$p_X(x) = \frac{1}{\ell} \exp - \frac{x}{\ell} \quad (\ell = \text{average message length})$$

And

$$A_n = \exp - \frac{nL}{\ell}$$

The fraction of frames of length L is obtained using analytical methods for the summation of series:

$$\beta = 1 + \frac{1}{u} (1-u) \log_e (1-u)$$

Where: $u = A_1 = \exp - \frac{L}{\ell}$

These equations and the approximate expression given above for $p_Y(y)$ completely determine the length of frames.

The use of length distributions to compute delays requires three quantities: the mean and standard deviation of length, and the Laplace transform $P^*_Y(s)$ of $p_Y(y)$. These quantities are obtained below. Also, the number λ_F of frames per unit time is obtained as a function of the number λ of messages per unit time.

The mean $\bar{Y}$ and standard deviation σ_Y are obtained from $p_Y(y)$ above, giving:

$$\bar{Y} = L - (1-\beta)\frac{L'}{2}$$

$$\sigma_Y = \left\{ \frac{(1-\beta)(1+3\beta)}{12} \right\}^{\frac{1}{2}} L$$

$P^*_Y(s)$ is obtained from $p_Y(y)$ by taking the Laplace transform, giving:

$$P^*_Y(s) = \beta \exp(-sL) + \frac{(1-\beta)}{sL'} \left\{ \exp(-sL) - \exp(-sL_H) \right\}$$

The *rate of frame arrivals* λ_F is obtained in terms of λ by setting an equilibrium condition: the average number of information bits per unit time remains constant after messages are broken into frames.

$$\lambda_F (\bar{Y} - L_H) = \lambda \bar{\ell}$$

After substituting the values of $\bar{Y}$ and L_H, this gives

$$\lambda_F = \frac{2\lambda \bar{\ell}}{(1+\beta) L'}$$

APPENDIX H

SWITCH TO CONCENTRATOR OUTPUT QUEUEING PROCEDURE

The NADIN specification describes the functional characteristics of switches and concentrators and their expected performance, and leaves the choice of design to the NADIN contractor. The functional constraints imposed on the switch operation by the NADIN specification dictate the switch output queueing procedure, as explained below. Using this queueing procedure an analysis of delays showed that the FSAS files cause other NADIN messages to suffer large delays. A different switch operation which prevents these delays is suggested below (See also Reference 27).

Switch Operation: The following functional constraints on switch operation are given in the NADIN specification:

- Continuity of messages: For low speed terminals which cannot reassemble the frames of a message, the interframe delay shall not exceed the time it takes to transmit one character, making the delay virtually imperceptible to an operator. (Reference: NADIN Specification, Paragraph 3.3.2.2.6)

- Flow control between switch and concentrator: The switch will not send a frame to a concentrator until it receives a message indicating that the output port to which the frame is destined is free or about to be free. This procedure prevents frames from arriving at the concentrator faster than they can be retransmitted over a low or medium speed output line. (Reference: NADIN Specification, Paragraph 3.3.2.10.5)

- Switch output priorities: The switch has four levels of internal priorities and messages are queued for output according to these priorities. (Reference: NADIN Specification, Paragraph 3.3.2.2.8.)

- Link priorities: Messages are transmitted according to two levels of link priority. The first link priority is the same as the first internal priority. The

second link priority is assigned to messages of internal priorities 2, 3 and 4. (Reference: NADIN Specification, Paragraph 3.3.2.2.8.1)

In addition to the above constraints, it is evident that the switch must not leave the line to a concentrator idle if messages are available and if the concentrator can accept their transfer. To satisfy these requirements combined with the necessity for continuity of messages and flow control, the following procedure may be used: if a message composed of several frames is selected for outputting the switch will send only the first frame and wait for permission from the concentrator to send the next frame (flow control). Instead of staying idle, it will then bring for output another message (destined to a different output port) and send the first frame. The switch will therefore service as many ports as possible, interspersing their frames. Also, the switch will bring in a new message for output only if no frame from messages currently partially transmitted can be sent. Therefore, the constraint on interframe delay will be automatically satisfied most of the time. Figure H.1 represents the switch mode of operation, including the effect of priorities. On the left, messages ready for output are stored in some form of mass storage (e.g., disk). On the right, messages in the output buffer are being transmitted, sharing the switch to concentrator line on a frame by frame basis. The next frame to be transmitted is chosen in *a round-robin fashion* (asynchronous time division multiplexing) with the exception of messages with the high link priority which are always given precedence (these constitute a very small portion of all messages). The transfer of a message from the mass storage into the buffer occurs only if there are not enough frames to keep the switch to concentrator line continuously busy.

The switch service discipline just described satisfies all the constraints given in the NADIN specification and is therefore a reasonable representation of a switch design based on the specification. For the NADIN level I traffic this service discipline is adequate since the speeds of output lines at the concentrator end are smaller than the speed of the switch to concentrator line. For instance, a message of Priority 2 will be transferred from mass storage to the output buffer and transmitted over a trunk line, even though a message of Priority 4 is also currently being transmitted, because the latter message does not monopolize the switch to concentrator line capacity.

Two features of the FSAS traffic combine to change this desirable performance. First, the AWP and FSDPS are colocated with the NADIN switches and concentrators and will be able to transmit and receive data at speeds much higher than the 4.8 Kbit/s speed of

the switch to concentrator line. Second, a portion of the FSAS traffic consists of file transfers which create NADIN messages lengths of 16 frames (approximately 4000 characters). In light of the discussion of the switch service discipline above, this means that an FSAS message of 16 frames, once transferred to the output buffer, will remain there alone and monopolize the switch to concentrator line for the time it takes to be transmitted (approximately 7 seconds on a 4.8 kbs line). A message of any priority arriving at such a time will thus have to wait for several seconds, a time violating the maximum delays recommended in the NADIN specification. The duration of a busy period during which such delays occur depends on the length of a file and on the speed of the switch to concentrator line. For example, Surface Observations (which are transmitted at the beginning of every hour) keep the switch to concentrator line constantly busy for 7 or 8 minutes. With a 9.6 Kbits/s line between switch and concentrator the corresponding duration is about 2 or 3 minutes. It can be argued that if the total duration of busy periods each hour is less than 6 minutes (i.e., 10% of the time), then both the average and 90th percentile delay requirements of the NADIN specification can be satisfied. It is better, however, not to take this approach, since the delays of messages in NADIN will become unacceptable if the FSAS makes changes in its schedules. (For instance, AFOS graphics may be sent in succession instead of more or less randomly). Accordingly, the average of delays over the duration of a busy period, rather than over a whole hour, must satisfy the requirements of the NADIN specification. These large delays of NADIN I messages caused by FSAS messages suggest a different switch operation where the switch directs its attention equitably to all users.

Modified Switch Operation: Delays at the times of file transfers can always be decreased by increasing the speed of switch to concentrator lines. An alternative to this "brute force" approach is to modify the switch service discipline in a way which prevents monopolizing use of the circuit by the file transfer messages. This may be done by altering the queueing discipline described above to give a more "fair" treatment to non-FSAS traffic. This approach is more fundamental than increasing line speeds between switch and concentrator, because it addresses the basic question of how to expand NADIN into a network which accommodates large file transfers, in addition to short messages. Considering the developmental stage of NADIN, it is also less expensive since it can still be accommodated in the design phase and does not require costly hardware (high speed modems, biplexers).

The modification in the switch service discipline consists of transmitting one frame at a time from each message destined to an idle output port. Referring to Figure H.1, this means that on the right, and for each output port at the concentrator, there is a buffer space containing a message destined to that port, if available, regardless of the presence of other messages in the output buffer. Clearly, this remedies the blocking of messages of Priority 1, 2 and 3 by FSAS file messages of Priority 4, since the delay imposed by FSAS messages is the time to transmit one frame rather than 16 frames (an FSAS message of Priority 1, 2 and 3 will still have to wait for the transmission of a full 16 frame message, since both are going to the same port and since aborting partially transmitted messages is not envisioned). The modified switch discipline outlined above will not automatically ensure the continuity of messages, as was previously the case before modifications, since the switch may send several frames destined to different ports before returning its attention to a message under transmission. However, for the configurations and traffic anticipated for the combined Level I and FSAS, such a situation is not expected to occur. If for future configurations and traffic, the situation becomes more likely, then a combination of the basic discipline and "fairness" approach may be required. Such a combination may be achieved by simply limiting the round-robin to a parametrically set number n of active ports. That is, bring a new message into the round robin transmission whenever the number of messages in the round robin drops below n.

The impact of the FSAS file transfer traffic is events of long delay. If these events are to be avoided, the queueing procedure employed at the switch must be such to disallow monopolizing of the switch-to-concentrator circuit by such traffic (or else the configuration must be changed). An n-limited round robin discipline is one such procedure. Because the value of n to ensure concentrator message output transmission continuity is expected to be large in comparison to the number of ports with messages in queue with NADIN I and FSAS traffic, the performance of the discipline can be reasonably approximated by an unlimited round-robin model. The appropriateness of this approximation can be readily determined from the results of its application. If it shows end-to-end delays for message transfers over the concentrator-to-switch circuit of greater duration than their nominal transmission time over the concentrator output circuit, then the parameter n must be considered.

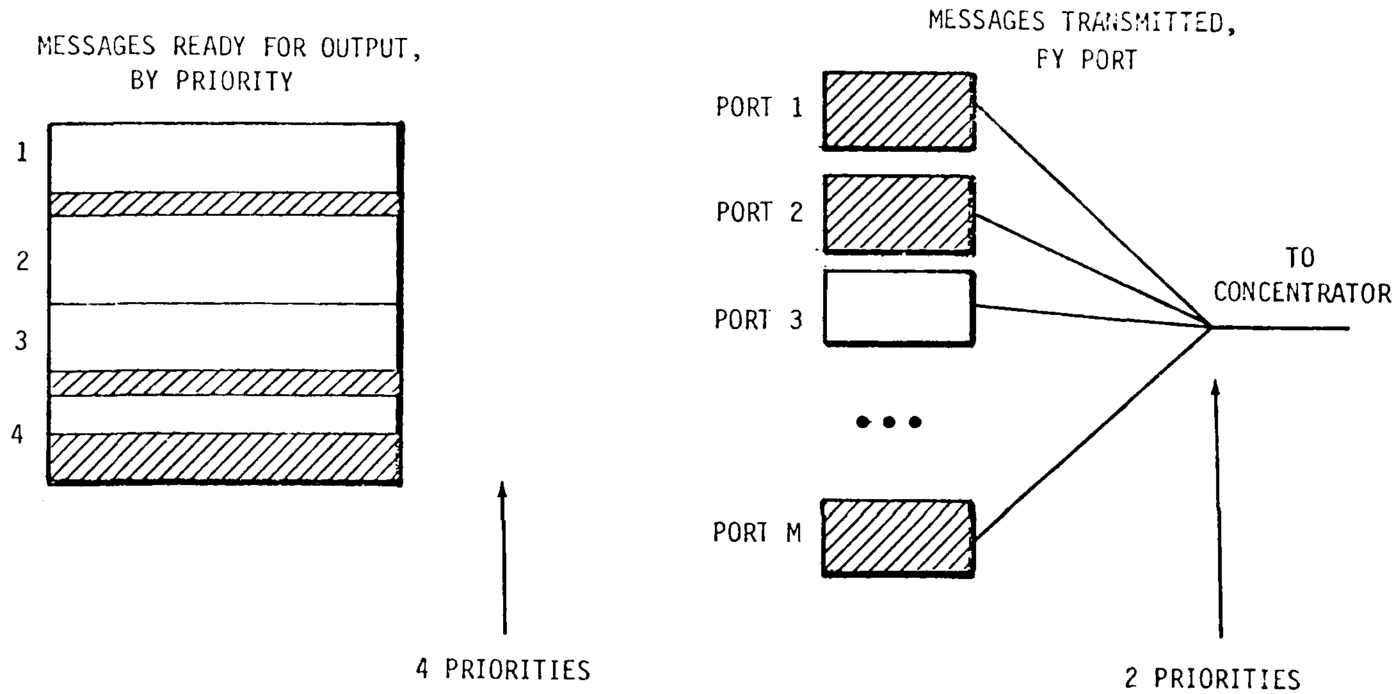


FIGURE H.1: NADIN SWITCH OUPPUT OPERATION

APPENDIX I

PROBABILITIES OF LARGE DELAYS AND LONG QUEUES

In Appendix M, the models of NADIN links are analyzed to compute average message delays and average queue sizes at NADIN nodes. An additional insight on the performance of NADIN can be gained from knowledge of the probabilities of large delays and long queues. These quantities are calculated here: $90^{\underline{th}}$ percentile delays and $95^{\underline{th}}$ percentile buffer occupancies. Defining these quantities by an example, a $90^{\underline{th}}$ percentile delay of 2.4 seconds means that 90 percent of the messages have a delay of less than 2.4 seconds. Similarly, the $95^{\underline{th}}$ percentile occcupancy is the buffer size that waiting messages do not fill 95% of the time. The choice of 90% for delays is dictated by the NADIN performance constaints (Appendix D) while the choice of 95% for buffer is arbitrary. If needed, the analysis developed in this appendix can be used for any other choices of percentile values. In t' ; case of known buffer size, the probability P_{of} of buffer overflow is a more useful quantity than the percentile buffer size. However, since the design of buffer size is beyond the scope of this study, the value of $95^{\underline{th}}$ percentile buffer size is retained here as a measure of NADIN's memory requirements.

The calculation of percentile delays and buffer use is based on a bound on the tail of the waiting time distribution by Kingman (Reference 22). Section B.1 proves the relation between delays and buffer sizes. Section B.2 describes the result obtained by Kingman. Sections B.3 and B.4 obtain percentile delay and buffer for a single link in NADIN. Section B.5 obtains the $90^{\underline{th}}$ percentile delay of a message going through several links in NADIN, by convolution of an exponential waiting time distribution. Section B.6 obtains the $95^{\underline{th}}$ percentile buffer occupancy of a node which handles several input and output links.

I.1 Relationship Between $k^{\underline{th}}$ Percentile and Buffer Overflow

B = buffer size a node reserves to waiting messages (characters)

b = buffer occupied by waiting messages (characters)

C = output line capacity (characters/second)

l = average length of messages or frames

w = waiting time

d_k = $k^{\underline{th}}$ percentile delay

P_{of} = probability of buffer overflow

A message ready for transmission and preceded by b characters has to wait a time w which is equal to b divided by the output link capacity C:

$$b = wC$$

In a strict sense, the random variable "b" only describes the size of buffer as seen by an arriving message. However, since the arrivals are Poisson and therefore "memoryless", b also describes the size of buffer at any instant of time.

The $k^{\underline{th}}$ percentile delay d_k and the probability of buffer overflow can now both be expressed in terms of waiting time probabilities as follows:

$$\text{Prob}(w \quad d_k) = k$$

$$P_{of} = \text{Prob}(b > B) = \text{Prob}(w \geq \frac{B}{C})$$

The two equations above are similar but would be used differently in general. In the first case the probability k is a given and the delay d_k has to be obtained, while in the second case the delay $\frac{B}{C}$ is given and the probability P_{of} has to be obtained. (However, since the design values of buffer sizes are unknown, $k^{\underline{th}}$ percentile delays are computed here). Both equations, nonetheless, require the evaluation of $\text{Prob}(w \geq y)$. An estimate of this probability is given by the Kingman's bound.

I.2 Kingman's Bound

The Kingman bound is an upper bound on the waiting time distribution of the (very general) G/G/1 queue. It is an exponential function of time with an exponential coefficient s_0 which depends on the arrival and service time distributions.

$$\mathrm{Prob}(w > y) \le \exp - s_0 y$$

$$s_0 = \sup(s:\ s \ge 0\ ,\ A^*(s)\, S^*(-s) \le 1)\ .$$

A*(s) and S*(s) have their previous meaning and are the Laplace transforms of the arrival time and service time pdf's, respectively. Sup (supremum) denotes the lowest upper bound. Replacing A*(s) by its value for Poisson arrivals:

$$s_0 = \mathrm{Sup}\ \left(s \ge 0 : \frac{\lambda}{s+\lambda}\ S^*(-s) \le 1\right)$$

The value of s_0 can be obtained from this equation by replacing the R.H.S. inequality by an equal sign and solving the resulting equation. S*(s) is the Laplace Transform of the service time distribution, assumed Gaussian in this report.

I.3 Evaluation of d_k

If d_k is the $k^{\underline{th}}$ percentile delay, it is conservatively estimated by:

$$\mathrm{Prob}(w \ge d_k) \le \exp - s_0\, d_k = 1-k$$

$$d_k = - \frac{\ln(1-k)}{s_0}$$

For example, to get the $90^{\underline{th}}$ percentile delay:

$$k = 0.9$$

$$1 - k = 0.1$$

$$d_k = \frac{\ln(10)}{s_0}$$

Proof: By direct substitution in the Kingman bound, it is clear that d_k is a conservative estimate since, if $d \ge d_k$, then:

$$\text{Prob}(w \geq d) \quad \leq \text{Prob}(w \geq d_k) \quad \leq 1-k$$

Therefore:

$$\text{Prob}(w \leq d) \quad \geq \; k$$

I.4 Evaluation of P_{of}

The probability of overflow P_{of} is obtained by direct substitution in the Kingman's bound:

$$P_{of} = \text{Prob}(w \geq \frac{B}{C})$$

$$\leq \exp - (s_0 \frac{B}{C})$$

The $95^{\underline{th}}$ percentile buffer occupancy is the value of B which makes the L.H.S. above equal to 0.95.

I.5.A Evaluation of d_k for a Network of Queues

While the delay of a message going over several NADIN links is the sum of the delays over each link, it is not true that the overall $90^{\underline{th}}$ percentile delay is the sum of $90^{\underline{th}}$ percentile delays over each link. In the case of two links, the problem is:

Given that:

$$\text{Prob}(w_1 \geq x_1) \quad \leq \exp - s_1 x_1$$

$$\text{Prob}(w_2 \geq x_2) \quad \leq \exp - s_2 x_2$$

What is:

$$\text{Prob}(w = w_1 + w_2 \;>\; x)$$

It is relatively simple to solve this problem because the R.H.S. of each of the first two inequalities above is the probability that an exponentially distributed time exceeds x_1 or x_2. Precisely, let w'_1 be a random variable with a pdf p_1, given by:

$$p_1(x) \quad = \quad s_1 \exp -s_1 x$$

It is then easy to verify that the first inequality can be rewritten as:

$$\text{Prob}(w_1 \geq x_1) \leq \text{Prob}(w'_1 \geq x_1)$$

The solution of the problem stated above is directly solved in the general case of m links. Let $w_1, \ldots w_m$ be the waiting times on each of m successive links and let the exponents of the Kingman bound be $s_1, \ldots s_m$. Define random variables $w'_1, \ldots w'_m$ with pdfs $p_1, \ldots p_m$ given by:

$$p_i(x) \quad = \quad s_i \exp - (s_i x) \qquad i=1, \ldots m$$

Then on each link:

$$\text{Prob}(w_i \geq x_i) \leq \text{Prob}(w'_i \geq x_i) \qquad i=1, \ldots m$$

It can be shown, assuming that waiting times as different links are independent, that these equations imply (See I.5.B below):

$$\text{Prob}(w = w_1 + \ldots w_m \geq x) \quad \text{Prob}(w' = w'_1 + \ldots w'_m \geq x)$$

The L.H.S. is the probability which has to be estimated. The R.H.S. is easy to evaluate because the w'_i have exponential distributions. Specifically, the Laplace transform of the pdf of w' is the product of the Laplace transforms of the individual p'_is. Doing this and taking the inverse Laplace transform gives:

$$\text{Prob}(w = w_1 + \ldots w_m \geq x) \leq \sum_{i=1}^{m} k_i \exp - s_i x$$

$$k_i \quad = \quad \sum_{j \neq i} \frac{s_j}{s_j - s_i}$$

I.5.B Proof of Inequality Regarding Sum of Variables

The above inequality is proved for m=2. The general case easily follows by induction on m. All integrals below are w.r.t. the "dummy" variables m.

$$P_r (w_1 + w_2 \geq x) = \int Pr (w_1 \geq x\text{-}w_2 \mid u)\, p_2 (u)\, du$$

$$= Pr (w_1 \geq x\text{-}u)\, p_2 (u)\, du$$

$$\leq Pr (w_1' \geq x\text{-}u)\, p_2 (u)\, du$$

$$= Pr (w_1' + w_2 \geq x)$$

$$= Pr (w_2 \geq x\text{-}w_1' \; u)\, p_1'(u)\, du$$

$$= Pr (w_2 \geq x\text{-}u)\; p_1' (u)\, du$$

$$\leq Pr (w'_2 \geq x\text{-}u)\, p_1' (u)\, du$$

$$= Pr (w'_1 + w'_2 \geq x)$$

I.6 Evaluation of Total Buffer Occupancy for Several Queues

A NADIN switch or concentrator simultaneously holds several queues which dynamically share the same buffer. It is necessary in that case to have an estimate of the probability of overflow of the buffer in the presence of all queues. The analysis of that problem is similar to the analysis done above since the probability that a sum of random variables exceeds a certain value is again required. However, for a switch, the values of s_i are equal for all twelve concentrator output lines (m in general). Again, the Laplace transform of w' is the product of the Laplace transforms of the individual p_i's. Taking inverse Laplace transform gives:

$$\text{Prob } (w \geq x) \leq (s_0 x)^m \int_1 u^{m-1} \exp - (s_0 xu)\, du \,/\, (m-1)\,!$$

The R.H.S. can be bounded using an approximation of the integrand near its maximum to give:

$$\text{Prob } (w \geq x) \leq \frac{(s_0 x)^m \exp - (s_0 x)}{(m-1)!\,(s_0 x - m + 1)}$$

and, the previously derived equation for the probability of overflow is the n used:

$$P_{of} = \text{Prob } (w \;\; B/C)$$

APPENDIX J

NADIN COMMUNICATION PROTOCOLS

The exchange of information in NADIN occurs simultaneously at the physical, link and message levels (Figure J.1). The physical protocol comprises the electrical characteristics of the line interface with NADIN nodes and is in accordance with EIA Standard RS-422 and RS-449 (Reference 24). NADIN's link protocol is the "Advanced Data Communication Control Procedures" (ADCCP), which basic unit is a frame. At the message level, information is in the form of NADIN messages composed of up to 16 ADCCP frames. The heading of the NADIN message contains control information interpreted by the switches and concentrators to process the message.

The structure of ADCCP frames and NADIN messages is described, followed by a calculation of the overhead associated with each.

J.1 ADCCP Protocol and NADIN Messages

Link Protocol: The NADIN link protocol is ADCCP which controls information transmission between stations (nodes). The information is divided into frames of at most 2048 bits, of which 48 are used for the protocol implementation. Figure J.2 shows the structure of an ADCCP frame. The flags mark the start and end of a frame and consist of the sequence 01111110. The address is the link address of the station receiving the frame and consists of 8 bits. A link address can be reused on different links of the same network. The control field contains the sequence numbers of the next frame to be received and to be sent by the transmitting station. The information field contains from 0 to 2000 bits and can consist of either data or ADCCP commands. The Frame Check Sequence (FCS) consists of the coefficients of a 15th degree binary polynomial. This polynomial is the additive inverse of the remainder of division of the ADCCP frame (excluding flags) by the CCITTV.41 generator polynomial P(X) ($X^{16} + X^{12} + X^5 + 1$). If no errors occur during transmission, the remainder of division of the received frame (including the FCS) will always be the same (0001110100001111).

The choice of a maximum block length is a trade-off between header overhead for small block lengths and erroneous frame retransmissions overhead for large block lengths.

The choice of 2048 bits is adequate considering the usual error rates of the conditioned 3002 lines used in NADIN. The address and control fields can each be used in either basic or extended modes.

In the basic mode the address field has 8 bits and can accommodate 126 locations (00000000 is not used, 11111111 is a universal address). In the extended mode, the address field can have as many 8 bit octets as desired and the total number of addressable stations is 62 (for the first octet) times 64 for each following octet. The first bit in each octet indicates whether this is the last part of the address or not. In NADIN, the extended mode format is used even if only one octet is present.

In the basic mode, the control field has 8 bits and allows a maximum of seven frames to remain outstanding (i.e., unacknowledged). In the extended mode, the control field has 16 bits and allows a maximum of 127 frames to remain outstanding. The mode of the control field is set by special ADCCP commands. The use of the basic control field is recommended in NADIN since the extended control field is normally used only for channels with a long propagation delay (e.g., satellite channels).

NADIN Message Structure: A NADIN message is composed of at most 16 ADCCP frames containing at most 3888 characters (after subtraction of ADCCP and Communication Control Field (CCF) characters). The NADIN specificat on sets a slightly smaller maximum of 3700 characters, equal to the maximum block length handled by the Weather Message Switching Center (WMSC).

The information part of a NADIN message is preceded by a group of characters which provide the information needed by the switches to identify the processing needed by messages. Table J.1 lists the different types of information in the heading. The table gives the minimum and maximum length in characters of each type of information, if included, and a short descriptive comment. It also indicates whether the information will definitely be included in FSAS messages or whether a decision must still be made. The last column indicates the cases where coordination between the FSAS and NADIN programs is needed. The information on the last two columns of Table J.1 does not exclude tailoring the NADIN message heading to specific FSAS applications. It is conceivable, for instance, that the date-time group be omitted altogether and that the address of message originator be either provided by NADIN or omitted. Finally, the NADIN program has not decided yet what use to make of the Optional Data Subfield C. So, if the FSAS program needs additional management or supervisory information not already present in NADIN messages it should

notify the NADIN program for possible inclusion in Subfield C (no such need has been identified in this study).

J.2 Protocols Overhead

The total traffic loading of NADIN by FSAS messages consists of the actual information content of the messages plus the extra messages, characters, or bits, which are introduced at the message and link levels to ensure proper routing, correctness, etc. These various types of overhead are identified below for link and message protocols. The overhead which consists of a fixed number of extra characters is added to the lengths of various types of messages. The overhead which results in an amplification of the number of bits per message or messages per hour is expressed as a percentage.

J.2.1 Link Protocol Overhead

From the description of the ADCCP protocol above the following link protocols overheads are identified (see Figure J.2):

Header and Trailer: The header and trailer in the basic mode consist of 48 bits: start flag, address, control field, frame check sequence and stop flag (during periods of continuous transmission of frames one stop flag can be the start flag of the next frame and the overhead is only 40 bits). As an example, for a 125 character message the header and trailer overhead is 4.8%.

Zero Insertion: A flag consists of the sequence 01111110. This sequence may occur in the frame bit stream between flags. To prevent it from being erroneously interpreted as a flag, the transmitter inserts a zero in the bit stream whenever it detects five successive ones. In a previous study made for one of NAC's clients, it has been shown that, assuming a random bit pattern, the average number of bits transmitted until a zero is inserted in $2 \times (2^5 - 1) = 62$ bits and this results in an average overhad of $1/62 = 1.6\%$ (the analysis consists of constructing a Markov Chain with states k=0, 1, ..., 5 and a random variable x_k equal to the number of bits transmitted before the next zero is inserted given a current string of 5-k ones). If the assumption of random bit patterns is relaxed, the zero insertion overhead can be lower (e.g., ASCII coded characters) or

larger (graphics containing long streams of ones) but it cannot exceed 1/5 = 20% in any case. The average overhead of 1.6% bits is retained in this study.

Retransmitted Frames: Frames which contain errors and subsequent frames are retransmitted. It is shown in Section J.3 below that by assuming a bit error probability of 5×10^{-6}, and an average of 4 retransmitted frames for each detected incorrect frame, the average overhead is 2.5%. This value is used in this study.

Supervisory and Management Frames: The ADCCP uses several types of supervisory and management frames which are usually short. No attempt at enumeration is made and the overhead is estimated to be a maximum of 3% extra messages.

J.2.2 Message Protocol Overhead

The main contribution to overhead at the message level is due to supervisory information in the heading. It is not yet clear what amount of NADIN supervisory information will be appended to FSAS messages. As a working assumption it is assumed that the total of header and trailer characters is 36 and that the optional data field contains 27 characters (half the maximum of 54 characters specified in the *NADIN specification*) giving a total of 63 extra characters. At the other extreme, it is assumed that if the NADIN and FSAS program make a concerted effort to reduce the overhead, there will be 20 extra characters.

There is also overhead due to NADIN system management messages. Without attempt at enumeration this overhead is assumed to contribute a maximum of 3% extra messages.

J.2.3 Summary of Link and Message Protocol Overheads

The link and message protocols result in a fixed number of characters added to each message, in an amplification of the number of bits (zero insertion) and in an amplification of the number of messages (ADCCP and NADIN supervisory and management frames).

The extra characters added are 11 characters per ADCCP frame and either 20 or 63 characters per NADIN message.

The extra bits due to zero insertion are 1.6%, i.e., the length of messages should be mulitplied by 1.016.

The extra messages are 2.5% for retransmission of erroneous frames, 3% for ADCCP command frames and 3% for NADIN management messages. Cumulating these multiplicatively, the number of messages per unit time is multiplied by 1.087.

J.3 Overhead Due to Retransmitted Erroneous Frames

When the receiving station detects one or more errors in a frame it rejects it. Eventually, the transmitting station knows that the frame was rejected and retransmits it as well as all the subsequent frames. Since the number of unacknowledged frames ranges from 0 to 7, it is assumed that whenever an error occurs an average of 4 frames are retransmitted. Of course, it is possible that one or more of these frames be in error. The following sequence of events can happen when Station A transmits a frame to Station B, given that p is the probability that a frame is erroneous.

A Transmits	B Transmits	With probability
1 information frame		1
	1 supervisory frame	p
4 information frames		p
	1 supervisory frame	p^2
4 information frames		p^2
...	...	

As a result:

$$\text{Expected number of overhead frames} = p + 4p + p^2 + 4p^2 + \ldots$$

$$= 5p + 5p^2 + \ldots$$

$$= \frac{5p}{1-p}$$

This model assumed that bi-directional transmissions between Stations A and B occur on the same link while in effect, with a full duplex connection between FSAS and NADIN, traffic in opposite directions actually goes on separate lines. However, the above model remains valid, assuming that traffic is the same in both directions, since the overhead figure on the A to B link, say, can be interpreted as the superimposition of retransmission and supervisory frames going from A to B.

The probability p that a frame of m bits is incorrect is now computed. With a bit error rate BER, p is equal to one minus the probability that none of m bits of the sequence is in error.

$$p = 1 - (1-BER)^m$$

assuming a bit error rate of 0.5×10^{-5} and assuming 1000 bits in a frame gives:

$$p = 0.004988$$

and the average overhead is, from the above equation:

$$\text{Overhead} = 2.5\%$$

Name of Header	Length Min	Length Max	Length Assumed	Comment	To be Used by FSAS	Choice of characters to be entered
Message Heading						
Start of heading	2	2	2	Same for all messages	Y	N
Supervisory information	2	69	7	Transmission identification. Not mandatory when recovery is not required.	N.D.	F,N
Priority	2	2	2	One of seven priorities	Y	F,N
Addresses	4m	9m	9	One message can go to m locations	Y	F,N
Date Time group	6	6	6	Day, hour and minute message was prepared.	Y	F
Message originator	4	9	9	Address of originator	Y	N
Length Subtotal	20		35			
Subfield A of Optional Data Field						
Message type	3	8		e.g. Graphics, Baudot	Y	F,N
Privacy	2	2		Type of privacy	N.D.	F,N
Acknowledgement	1	1		Defines type of system acknowledgement	N.D.	F,N
Billing	1	1		Class of billing	N.D.	N
Text code and format	2	2		For non ASCII texts	N.D.	F,N
Text length	4	4		Mandatory for graphics	Y	F
Subfield B of Optional Data Field						
Authentication key	6	8		For privacy	N.D.	F,N
Possible duplicate message	3	3		Used in case accountability is needed during recovery	N.D.	F,N
File number	?	?		ADP file number	N.D.	F,N
Data Sequence Number	2	2		For messages exceeding 3700 characters.	Y	F
Subfield C of Optional Data Field						
Additional information now undefined.						
Total length for A,B,C			27			
Message Text	0	3700				
Message ending	1	1	1	ASCII ETX	Y	N
Total overhead	45	129	63			

Key: Y = Yes
N.D. = Not Decided
F = FSAS responsibility
N = NADIN responsibility
F,N = joint FSAS and NADIN responsibility

Table J.1: STRUCTURE OF NADIN MESSAGE

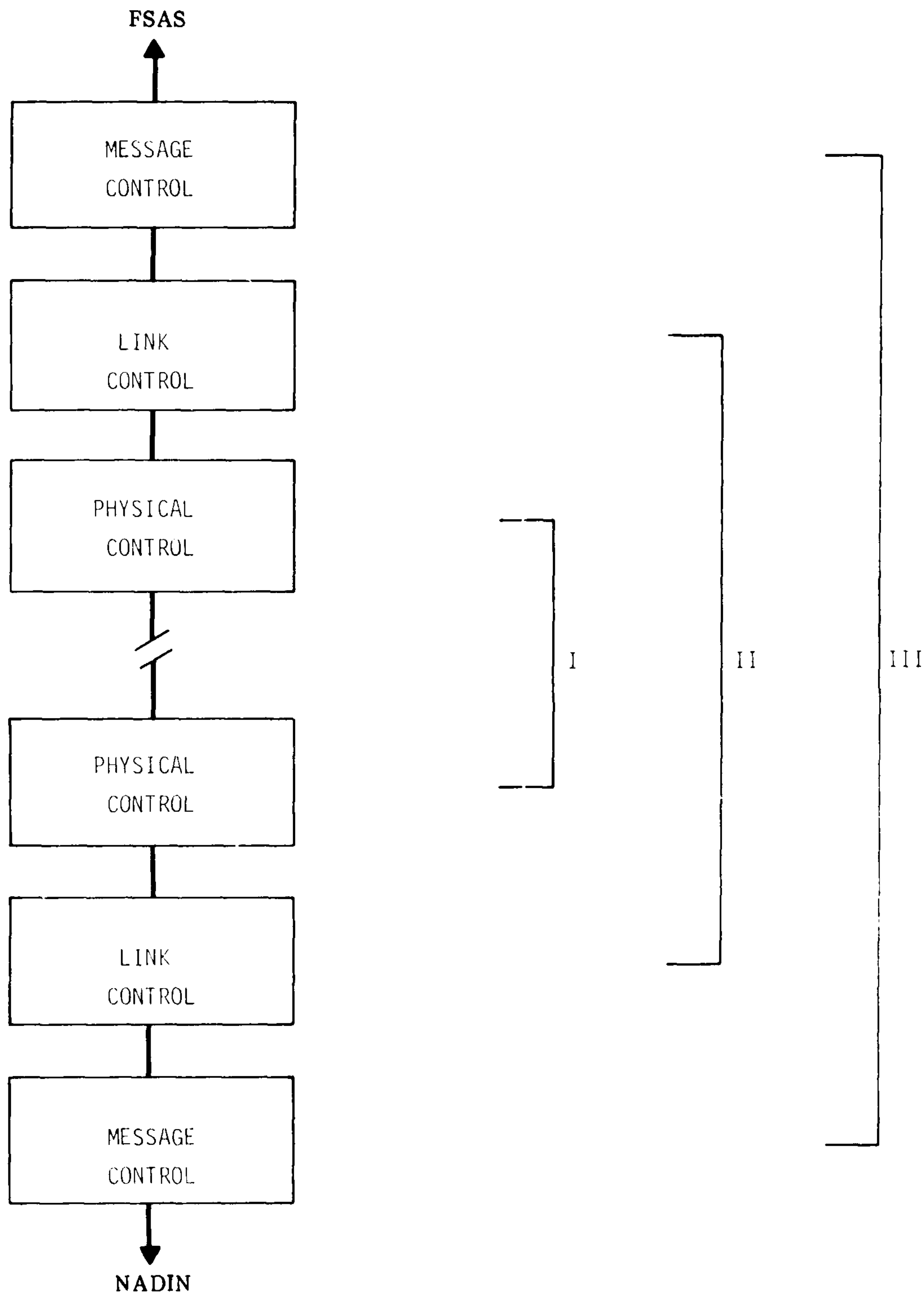


FIGURE J.1: **LAYERS OF PROTOCOL BETWEEN FSAS AND NADIN**

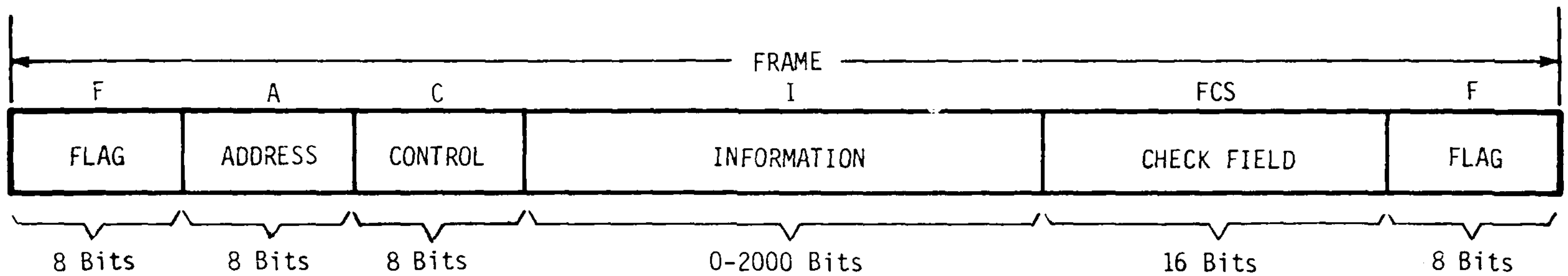


FIGURE J.2: ADCCP FRAME FORMAT

APPENDIX K

QUEUEING THEORY CONCEPTS AND RESULTS

All NADIN links are modeled as M/G/1 queues with the exception of the switch to concentrator links at the times of file transfers from AWP to FSDPS. The inputs to an M/G/1 model are traffic statistics: message length and arrival times. The outputs are average message delays. The explanation of an M/G/1 model and the model's results are given below. The assumptions and analyses made to put FSAS traffic statistics in a form usable in the M/G/1 model are also presented.

The concept of **server** is basic to queueing theory. A server is a utility which is in demand by several users, spends time servicing each, and requires users which arrive during the servicing of another user to wait. In the NADIN context, the **server** is a NADIN backbone line, **users** are messages, and the **service time** is the transmission time of a message over a NADIN backbone line, also equal to the number of bits in the message divided by the line speed in bits/sec. The system composed of a server and waiting users is a **queue**. The M/G/1 queue is a special type of queue: the interarrival times of messages are exponentially distributed (Markovian arrivals), the service times have a General distribution, and there is **1** server.

Definitions: The service time t_s (time of transmission over the line) of a message of x bits is given by:

$$t_s = \frac{x}{C} \text{ second}$$

The message length and service time distributions are therefore the same except for the factor C in their argument. In the NADIN's model used, message length statistics are replaced by service time statistics.

t_a = time between two message arrivals

$t_s = \frac{x}{C}$ = service time of a message

t_w = time a message waits for transmission of previously arrived messages

$t_q = t_s + t_w$ = "queueing" time or total time spent in system

The corresponding probability density functions are a(t), s(t), w(t) and q(t). For example,

$$a(t)\,dt = \text{Prob } (t_a \text{ is between } t \text{ and } t + dt)$$

The averages of the times defined above are denoted with a bar, e.g.,

$$\bar{t}_a = \text{Average } (t_a) = \int_0^\infty t\, a(t)\, dt$$

The standard deviation of times is denoted by σ, with the appropriate subscript, e.g.,

$$\begin{aligned}\sigma_s^2 &= (\text{Standard deviation of } t_s)^2 \\ &= \int_0^\infty (t - \bar{t}_s)^2\, s(t)\, dt \\ &= \overline{t_s^2} - \bar{t}_s^{\,2}\end{aligned}$$

The Laplace transforms of the probability density functions (pdf) are used to obtain 90th percentile delays (Appendix I). The Laplace transform of a pdf is denoted by the appropriate upper case letter, and an asterisk distinguishes it from the Probability Distribution Function (PDF), e.g.,:

$$A^*(s) = \quad \text{Laplace Transform of } a(t) \quad = \int_0^\infty e^{-st}\, a(t)\, dt$$

Similarly, the Laplace transforms of service time, waiting time and queueing time are $S^*(s)$, $W^*(s)$ and $Q^*(s)$, respectively.

In NADIN's model these operations on time distributions (average, standard deviation and Laplace transforms) are specialized to the exponential distribution for arrival times and to the Gaussian distribution for service times:

Arrival times: NADIN and FSAS traffics have only two types of arrival time statistics: scheduled and unscheduled. The scheduled arrivals are FSAS file transfers which occur at predetermined times. They are usually long and come to the NADIN over high speed lines, and are analyzed independently of the M/G/1 model in Appendix N. The interarrival time distribution of unscheduled messages is assumed throughout to be exponential. Mathematically:

$$a(t) = \lambda e^{-\lambda t}$$

λ = Average number of messages arriving each second.

Usually, exponential interarrival times adequately describe message arrivals in real networks and predict delays close to measured values (Reference 19). Messages with exponential interarrival statistics also have the "memoryless property": the arrival of a message is independent of past arrivals. This property simplifies the analysis of a queueing model developed in this study (Appendix M, Paragraph M.4).

From the definitions above it can be shown that the average, standard deviation and Laplace transform for exponential arrival times are:

$$\bar{t}_a = \frac{1}{\lambda}$$

$$\sigma_a^2 = \frac{1}{\lambda^2}$$

$$A^*(s) = \frac{\lambda}{s+\lambda}$$

Service times: The messages flowing in NADIN have widely different length distributions (i.e., service times). The length distributions encountered are the uniform biased exponential and normal distributions and each of these appears several times with different means and standard deviations. It is not possible to analytically handle all these distributions and an approximation is called for.

Let

m = number of different message types

$s_i(t)$ = service time distribution of message type i ($i = 1, 2, ..., m$)

λ_i = average number of messages of type i arriving each second

$\lambda = \lambda_1 + ... + \lambda_m$ = total number of messages arriving each second

$s(t)$ = aggregate service time time distribution.

It can be shown that:

$$s(t) = \frac{1}{\lambda} \left(\lambda_1 s_1(t) + ... + \lambda_m \; s_m(t) \right)$$

It is unwieldy to keep the different distributions $s_1, ..., s_m$ in the analysis of NADIN's model. The Gaussian (bell-shaped) distribution is a reasonable substitute for the aggregate service time distribution s(t). This Gaussian distribution is assumed to retain the mean and standard deviation of s(t):

$$s(t) \simeq \frac{1}{\sqrt{2\pi}\,\sigma_s'} \quad \exp - \frac{1}{2} \left(\frac{t - \bar{t}_s}{\sigma_s} \right)^2 \qquad t \geq 0$$

$$\sigma_s' = \sigma_s \left\{ 1 - Q\left(\bar{t}_s / \sigma_s\right) \right\}$$

where

$$Q(y) = \frac{1}{\sqrt{2\pi}} \int_y^{\infty} \exp -\left(u^2 / 2\right) \; du$$

$$\simeq \frac{1}{\sqrt{2\pi(y^2 + 1)}} \quad \exp - (y^2 / 2)$$

The last approximation is taken from Reference 20.

It remains now to calculate the mean and standard deviation of t_s as a function of the means and standard deviations of $t_{s_1}, \; ... \; , t_{s_m}$. A relatively straightforward calculation gives:

$$\bar{t}_s = \sum_{i=1}^{m} \frac{\lambda i}{\lambda} \bar{t}_{s_i}$$

$$\sigma_s^2 = \sum_{i=1}^{m} \frac{\lambda i}{\lambda} \sigma_{s_i}^{\ 2} + (\bar{t}_{s_i} - \bar{t})^2$$

Given $\bar{t}_s$ and σ_s, the pdf of service time distribution is completely defined by the Gaussian approximation for s(t). The Laplace transform of s(t) is obtained by integration, giving:

$$S^*(s) = \frac{\sigma s}{\sigma_s} \exp s \left\{ s/(2\,\sigma_s^2) - \bar{t}_s \right\} Q\,(s\sigma_s - \bar{t}_s/\sigma_s)$$

The arrival time and service time distributions to be used in the M/G/1 queueing model are now completely defined by their mean, standard deviation and Laplace transform. The mean and standard deviation of service time are also further defined in terms of the statistics of the various messages types.

Solution of the M/G/1 Queueing Model: Pollaczek and Khinchine solved this model and obtained the Laplace transform of the waiting time distribution as a function of the Laplace transform of the service time distribution. With a Gaussian service time distribution, the queueing time distribution cannot be obtained in closed form. However, a corollary to Pollaczek and Khinchine results gives the mean queueing time as a function of the mean and standard deviation of the service time (Reference 22) as follows:

Mean queueing time: The queueing time t_q is the sum of waiting and service time.

$$\bar{t}_q = \bar{t}_s + \bar{t}_w$$

The mean waiting time is given by

$$\bar{t}_w = \lambda \bar{t}_s^{\,2} \ (1 + \sigma_s^{\ 2} \ / \ \bar{t}_s^{\ 2}) \ /2\ (1 - \lambda \bar{t}_s)$$

In Appendix I, the 90th percentile waiting times are obtained independently of the M/G/1 model by using the Laplace transforms of the arrival time and service time distributions.

APPENDIX L

NADIN QUEUEING MODEL

The delays encountered by a message in NADIN are waiting delays (waiting for a line to be available) and transmission delays (length of message divided by speed of the line). The sum of these is called the queueing delay. This appendix presents a model of NADIN and indicates how total path delays are obtained from delays on links.

The method to obtain the queueing delay is to calculate the delay on each link of the message path and then sum up the delays. This "decomposition" of the network implicitly assumes that the arrival of messages at a link are independent across the network. This assumption usually gives good results, although it is not exact except in the case of exponential interarrival and transmission time distributions (Reference 19).

The analysis of delays in NADIN consists of isolating the three basic backbone links (switch to concentrator, concentrator to switch and switch to switch) and constructing a queueing model for each. After that is done, the message statistics are put into a form suitable for use in the model. Finally, the actual delay figures are obtained as a function of line speeds, eventually chosen to satisfy delay requirements. Delays are calculated in two different situations: at times of file transfers and at times between files transfers. The delays at the times of file transfer condition the design since these delays must conform to the limits set in the NADIN specification. At other times, delays are an indication of the better performance which can be expected by the user.

Link Decomposition: The purpose of modeling NADIN is to determine the delays incurred by messages when the FSAS traffic is added to the initial NADIN traffic and, accordingly, to determine the necessary line speeds in NADIN. The delays to be obtained are the delays of FSAS messages and the delays of the original NADIN traffic. These delays are obtained in two situations. First, at times of normal FSAS operation when only unscheduled messages are sent. And second, at times when large files are transferred from the AWP to the FSDPS or between the AWPs. To specify the delays obtained, Figure L.1 shows the different types of links modeled, labeled from A to G.

A is the link from switch to concentrator.

B is the link from concentrator to switch.

C is the link between switches.

D is the link from AWP to switch.

E is the link from switch to AWP.

F is the link from FSDPS to concentrator.

G is the link from concentrator to FSDPS.

The total delay of a message going from AWP to FSDPS, for example, is the sum of transmission delays over links D, A and G plus the delays waiting for transmission over links D, A and G.

In Section 3.4.3 three delays are defined: entrance delay t_E, network delay t_N and exit delay t_X. The entrance, network and exit delays are calculated for:

- FSAS Messages

  Unscheduled weather reports from AWP to FSDPS

  Flight plans from FSDPS to colocated or remote ARTCC

  Flight plans from one FSDPS to another FSDPS

- NADIN-I Messages

  From a device connected to one concentrator to a device connected to another concentrator, and such that the concentrators are connected to different switches.

An example shows how these delays relate to the delays on links A to G defined above. Consider the total delay incurred by a message going from an AWP to an FSDPS.

The message has to wait for access to the AWP to switch line and for transmission across the AWP to switch line. By the end of time t_E (entrance delay) the last character of the message is received at the switch. The entrance delay is thus equal to waiting time plus service time over link D from AWP to switch (Figure L.1).

Similarly, the network delay t_N of the messages is equal to the waiting time plus service time over link A from switch to concentrator.

The exit delay t_X is equal to the transmission time over link G from concentrator to FSDPS. The values of t_E, t_N and t_X for a message are therefore the sum of delays over

all links included in that message path. The delays over all links from A to G are calculated separately. The calculation of the $90^{\underline{th}}$ percentile delays over a path composed of several links is more complex and resolved in Appendix I.

Each link is modeled as an M/G/1 queue, with the exception of the link between the NADIN switch and the NADIN concentrator. That link is continually busy at times of file transfers and the assumption of Poisson arrivals is no longer correct. Link C between the switches is also a special case. This link physically consists of two 9.6 Kbits/s lines. It is assumed that one of these lines is dedicated to the FSAS traffic while the other is used to transmit the original NADIN traffic. This assumption is reasonable since it shields the original NADIN traffic from the effect of FSAS file transfer. In actual implementation, the FSAS and original NADIN traffic might be mixed over the two physical lines, but an adequate service discipline will give delays at least as good as the delays predicted here.

Finally, when the M/G/1 model is used to calculate delays on a link, it must be ascertained whether messages or frames are the basic unit of transmission. For instance, on the switch to concentrator links, messages going to the same concentrator output port follow each other, while messages going to different output port are interspersed.

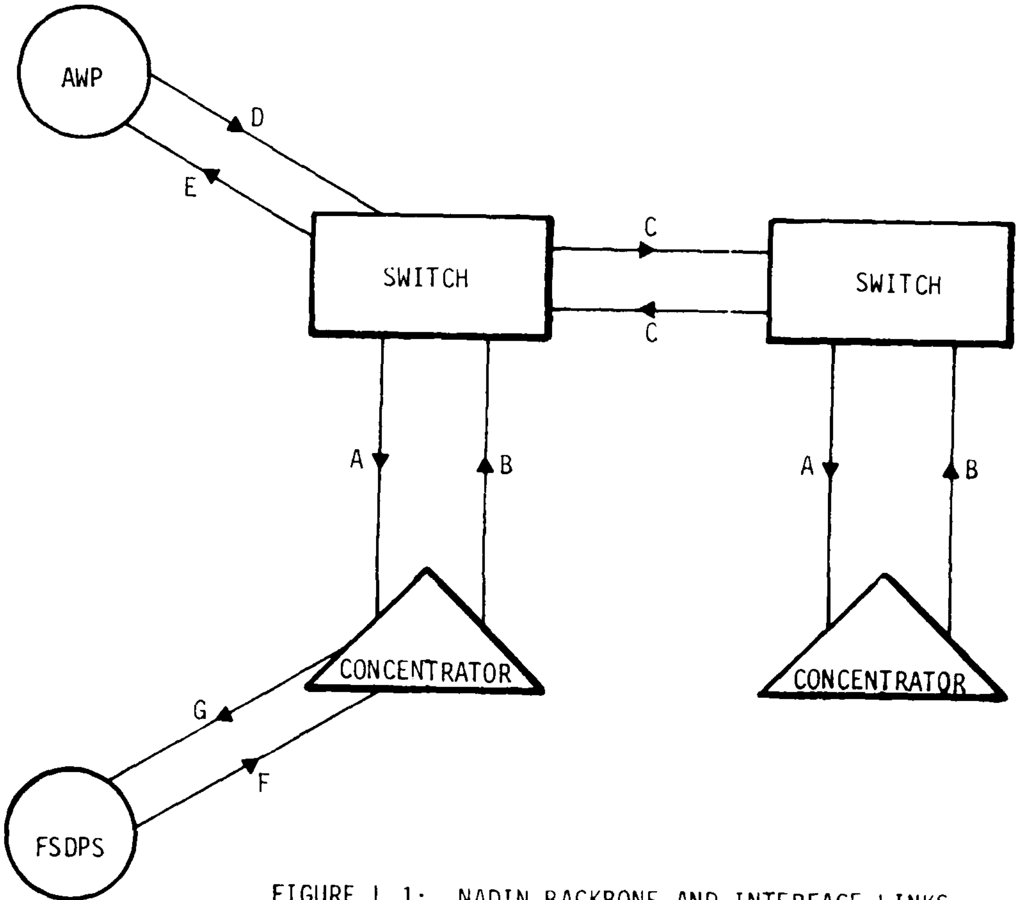


FIGURE L.1: NADIN BACKBONE AND INTERFACE LINKS

APPENDIX M

SWITCH TO CONCENTRATOR LINK MODEL: BUSY PERIOD

The NADIN switch to concentrator link cannot be modeled as an M/G/1 queue at times of file transfers because the AWP sends frames continuously, and arrivals no longer form a Poisson process. A special model developed here analyzes delays on the switch to concentrator link during file transfers. The analysis of that link depends on whether the switch output queueing procedure is consistent with the NADIN specification or whether it is modified. The analysis also depends on whether unscheduled FSAS messages or NADIN messages are considered.

The delays of unscheduled NADIN traffic with an unmodified switch operation obtained in M.1. The delays of NADIN traffic with a modified switch operation are obtained in M.2 with the details of the analysis in M.4 and M.5. Finally, Section M.3 considers the delays of FSAS messages.

M.1 Delays of Unscheduled Traffic (Unmodified Switch Operation)

An unmodified switch discipline means that a long FSAS file message can monopolize the switch to concentrator line once its transmission is started. A message arriving during the busy period has to wait approximately for the time it takes to transmit such a message and all other unscheduled messages arrived in the mean t me. Let

L: length of a file frame = maximum length of a frame = 2.048 Kb

C: capacity of switch to concentrator link

λ: total average number of frame arrivals per second for all NADIN I traffic (or FSAS unscheduled messages)

$\bar{x}$: average length of frames for NADIN I traffic (or FSAS unscheduled messages)

$\bar{t}_w$: average waiting time for NADIN I traffic (or FSAS unscheduled messages)

The time to transmit a file frame is L/C. The number of unscheduled frames arriving during such time is L/C, and each of these frames is transmitted in a time $\bar{x}/C$. On the average, a frame has to wait for half the time to transmit a file message of 16 frames and for the time to transmit the unscheduled frames arrived during that time. Therefore:

$$\bar{t}_w = \frac{1}{2}(16\ L/C + 16\ \ L\,\bar{x}\,/\,C^2)$$

This equation applies to both NADIN I traffic or unscheduled FSAS messages which have higher priority than file transfers.

M.2 Delays of Unscheduled Traffic (Modified Switch Operation)

The concentrator has m output ports (m=16 for the sum of initial NADIN traffic and FSAS traffic). Accordingly, the switch creates m queues, one for each of the output ports and takes at most one frame at a time from each queue. Let the first queue be composed of the messages going to the FSDPS. It is assumed that at the time of file transfers this queue is "infinite" in the sense that it will always have a frame available for transfer. The objective of analysis is to find the delays associated with each queue, except the queue of messages going to the FSDPS which is treated separately in M.3 below. The guiding idea in solving the problem of simultaneous queues is that each of them can be separately modelled as an M/G/1 queue. The "service time" seen by each of them is equal to the time of transmission over the switch to concentrator line plus the transmission time of messages going to other ports. Let:

$t_{s,k}$ = service time of a frame from queue k

$p_{k,0}$ = probability that queue k has no frames when examined by the switch ($p_{1,\,0}$ = 0 because there always are frames available from the AWP)

$t_{c,k}$ = time used to serve queue k in a cycle of the switch ($t_{c,k}$ = 0 if there is no frame in queue k).

T = time taken by the switch to go through a complete cycle of service to the m queues.

T_k = time taken by the switch to service all queues except queue k.

All the times above are assumed to be steady-state random variables. From the definitions:

$$t_{c,k} = \begin{cases} 0 & \text{with probability } p_{k,0} \\ t_{s,k} & \text{with probability } 1 - p_{k,0} \end{cases}$$

$$T = \sum_{k=1}^{m} t_{c,k}$$

In queue r, the service time of a frame appears to be the actual service time of the frame plus the time it takes for the switch to service the remaining queues. This apparent service time is denoted by $t'_{s,r}$:

$$t'_{s,r} = t_{s,r} + \sum_{k \neq r} t_{c,k}$$

So, queue r can be treated as an M/G/1 queue with a service time equal to $t'_{s,r}$. The average of this service time and its standard deviation are used in the Khinchine-Pollaczek (K-P) formula for delays to determine the average waiting time (not including the average service time). From the K-P equation given in Appendix K:

$$\bar{t}_{w,r} = \bar{t}'_{s,r}\, \rho_r\, (1 + \sigma'^2_{s,r} \,/\, \bar{t}^2_{s,r}\,) \,/\, 2(1-\rho_r)$$

$$\rho_r = \lambda_r\, \bar{t}_{s,r}$$

This average waiting time represents the average time a frame has to wait for frames already in the queue. When no frame precedes an arriving frame, this frame still has to wait a time T_r^* for the switch attention (to be calculated), and this occurs with probability $p_{r,0}$. The total queueing delay is the sum of these waiting times plus the actual transmission time over the switch to concentrator line.

$$\bar{t}_{q,r} = \bar{t}_{w,r} + p_{r,0}\, \bar{T}_r^* + \bar{t}_{s,r}$$

This equation gives the average value of total delay for all queues, except the FSAS queue. The first component, $\bar{t}_{w,r}$, was given above as a function of $\bar{t}_{s,r}$. and $\sigma'_{s,r}$. To calculate these quantities, it can be shown from the definition of $t_{c,k}$ and $t'_{s,k}$ that:

$$\bar{t}_{c,k} = (1-p_{k,0})\,\bar{t}_{s,k}$$

$$\sigma^2_{c,k} = (1-p_{k,0})\,\sigma^2_{s,k} + p_{k,0}\,(1-p_{k,0})\,\bar{t}^2_{s,k}$$

$$\bar{t}'_{s,r} = \bar{t}_{s,r} + \sum_{k\neq r} \bar{t}_{c,k}$$

$$\sigma^2_{s,r} = \sigma^2_{s,r} + \sum_{k\neq r} \sigma^2_{c,k}$$

The above quantities can be expressed in terms of the average and standard deviation of the cycle time T of the switch. First:

$$\bar{T} = \sum_{k=1}^{m} \bar{t}_{c,k}$$

$$\sigma^2_T = \sum_{k=1}^{m} \sigma^2_{c,k}$$

Then, using these expressions to calculate $\bar{t}'_{s,r}$ and $\sigma'^2_{s,r}$ gives:

$$\bar{t}'_{s,r} = p_{r,0}\,\bar{t}_{s,r} + \bar{T}$$

$$\sigma^{2\prime}_{s,r} = \sigma^2_T + p_{r,0}\,\sigma^2_{s,r} - p_{r,0}\,(1-p_{r,0})\,\bar{t}^2_{s,r}$$

The second component of the equation for total queueing delay is $p_{r,0}\,\bar{T}^*_r$. The value of $p_{r,0}$ is computed below. As for T^*_r, it is the time which a message arriving in queue r has to wait for the switch attention, provided queue r was empty. This time of cycle completion, or residual time, depends on the time T_r it takes the switch to service all the other queues. In Section M.4 below it is shown that the average of the residual time is a function of the average $\bar{T}_r$ and the standard deviation σ_r of the time T_r, as follows:

$$\bar{T}^*_r = \frac{\bar{T}_r}{2} + \frac{\sigma^2_r}{2\,\bar{T}_r}$$

To evaluate $\bar{T}_r$, and σ_r, it suffices to note that T_r is the difference between $t'_{s,r}$ and $t_{s,r}$, which are the time the switch takes to service all queues and the time the switch takes

to service queue r, respectively. Using this fact to calculate the average and standard deviation of T_r gives, assuming independence of T_r and $t_{s,r}$:

$$T_r = t'_{s,r} - t_{s,r}$$

$$\overline{T}_r = \overline{t}'_{s,r} - \overline{t}_{s,r}$$

$$= \overline{T} - (1 - p_{r,0})\, \overline{t}_{s,r}$$

$$\sigma_r^2 = \sigma'^2_{s,r} - \sigma^2_{s,r}$$

$$= \sigma_T^2 - (1 - p_{r,0})\, \sigma^2_{s,r} - p_{r,0}\,(1 - p_{r,0})\, \overline{t}^2_{s,r}$$

The values of $\overline{T}_r$ and σ_r are substituted above to give $\overline{T}_r^*$. This derivation of $\overline{T}_r^*$, which is the major component of the queueing time, is of general applicability and can be used if there are several file transfers, by different users, between switch and concentrator. In the special case when only FSAS file transfers are present, the above expressions can be interpreted intuitively to give a quick approximate estimate of queueing delays.

First, the time to service an FSAS frame is nearly constant, because most such frames are a full 256 characters. Second, the time to service an FSAS frame is the major component of the switch cycling time $\overline{T}$. These two facts together indicate that the standard deviation σ_T is small compared to the average $\overline{T}$. In practice, it will also be true that the probability $p_{r,0}$ that a port other than the FSDPS is idle is very close to 1, because the average traffic load of each port is quite small compared to the capacity of the switch to concentrator link. Putting these facts together, it turns out that:

$$\overline{T}_r^* \simeq \frac{\overline{T}_r}{2} \simeq \frac{\overline{T}}{2}$$

These approximations underestimate delays by only a small margin. To simplify the expression for queueing delay further the waiting time $\overline{t}_{w,r}$ is neglected because it is very small due to the low utilization of the switch to concentrator line by queue r. Summarizing these results:

$$t_{q,r} \simeq \frac{\overline{T}}{2} + \overline{t}_{s,r}$$

In words, the total queueing time of a message from queue r is approximately equal to half the time the switch takes to cycle around all queues plus the time it takes the switch to concentrator line to transmit a message from queue r. This approximation gives an intuitive understanding of the main factors influencing delays but exact expressions can be used for actual calculations. The exact expressions are necessary if non-FSAS users have high traffic or file transfers.

To calculate the exact value of queueing delay $\bar{t}_{q,r}$ it remains to evaluate the average cycle time $\bar{T}$ and the probabilities $p_{r,0}$ that a queue r is empty. In Section [illegible] below an analysis of the conjunction of all queues is made and it is shown as a result that

$$\bar{T} = \bar{t}_{s,1} / (1 - \rho')$$

$$p_{k,0} = 1 - \lambda_k \bar{T} \qquad k \neq 1$$

$$p_{1,0} = 1$$

$\bar{t}_{s,1}$ is the average service time of an FSAS frame.

$\rho' = \sum_{k \neq 1} \lambda_k \bar{t}_{s,k}$ is the utilization of the switch to concentrator line in the absence of FSAS traffic.

The results on queueing time given above are recapitulated by presenting an algorithm for the calculation of the total queueing time $\bar{t}_{q,r}$ of a message in queue r.

- The inputs consist of the average and standard deviation of the length of messages going to ports 2 to m and consist of the rate of arrival of such messages λ_r in number of messages per second.

- The average length of an FSAS frame is computed separately by analyzing the queue of messages at the AWP (Appendix N).

- All message lengths are divided by the speed of the switch to concentrator line to give service times.

- The utilization ρ' created by the non-FSAS messages is equal to the sum of products of arrival rates and service times.

- $\bar{T}$ is equal to the average service time of an FSAS frame divided by $(1 - \rho')$.

- The probabilities $p_{r,0}$ that a queue is empty are equal to one minus the product of $\bar{T}$ and ρ_r.

- The quantities $\bar{T}_r$ and ρ_r are computed and then the time $\bar{T}_r^*$ waiting for switch attention is evaluated.

- The quantities $\bar{t}'_{s,r}$ and $\sigma'_{s,r}$ are computed and the waiting time $\bar{t}_{w,r}$ in the queue is evaluated.

- The total queueing time $\bar{t}_{q,r}$ is given by:

$$\bar{t}_{q,r} = \bar{t}_{w,r} + p_{r,0}\,\bar{T}_r^* + \bar{t}_{s,r}$$

M.3 Delays of FSAS Messages (File Transfer Periods)

The FSAS unscheduled messages (e.g., VFR flight plans from one FSDPS to another) suffer more delays than other messages in NADIN, because they share the same output circuit (at the concentrator) with file messages. Since priorities are not preemptive, an FSAS message of priority 2 or 3 has to wait for the completion of transmission of any previously arrived file message.

A message going to an FSDPS that did not originate at the AWP is automatically handled in priority order by the switch. However the priorities of messages coming from the AWP must be established by the AWP. Messages of the same priority will be served in first-come-first-served order at the switch. So, unless the AMP interleaves these short unscheduled messages between file messages, they will not be sent until the file is transmitted (i.e., a message has to be sent early to be received early). Also, the presence or absence of flow control between an AWP and a NADIN switch has not effect on the delays of FSAS messages of priorities 2 and 3: in the case of flow control they will be sent by the AWP as soon as possible, and in the absence of flow control their higher priority will be

recognized by the switch. The delays of non-scheduled FSAS messages are also not affected by whether the switch service discipline as interpreted from the NADIN specification is changed or not. The modifications affect the servicing of messages going to different concentrator output circuits but messages going to the same output circuit still receive the same treatment.

The delays of FSAS unscheduled messages at the times of file transfers are the same as those to which NADIN I traffic would be submitted, if the switch operation as interpreted from the NADIN specification was not modified. Therefore, the delay equation in Section M.? also applies to FSAS messages.

M.4 Residual Life of Switch Cycle

The "residual" life of the switch cycle is the amount of time a message arriving in queue r has to wait until the switch gives it attention. The average of residual life is not equal in general equal to half the average cycle time. (A discussion of this apparent paradox is given in Reference 21, pp 169 - 176). The exact solution of the problem is given in Eq. 5.16 of that text and reproduced here in with appropriate change of notation:

$$\bar{T}_r^* = \frac{\bar{T}_r}{2} + \frac{\sigma_r^2}{2\,\bar{T}_r}$$

M.5 Switch Cycle Time and Probability of Concentrator Output Port Idleness

The probability $p_{r,0}$ that the output port r of a concentrator is idle is calculated, as well as the average time $\bar{T}$ the switch takes to service all the queues of frames destined to various output ports. The derivation relates the number of frames in the $r^{\underline{th}}$ queue in successive switch cycles. At steady state, the number of frames in successive cycles is the same random variable and therefore a set of equalities from which $p_{r,0}$ is obtained is established. Define:

P(m) = Probability of m frames in the queue when examined by switch (m=0, 1, ...)

t = Time since the switch last examined queue r, given that the queue was empty in previous cycle.

t' = Time since the switch last examined queue r, given that the queue was not empty in previous cycle.

x = $\lambda_r t$ = (Average number of arrivals during t).

y = $\lambda_r t'$ = (Average number of arrivals during t')

$Q(m)$ = Probability of m arrivals during t.

$R(m)$ = Probability of m arrivals during t'.

From the definitions of service times in Section M.1:

$$t = \sum_{k \neq r} t_{c,k}$$

$$t' = t_{s,r} + t$$

The steady state equilibrium conditions of the queue can now be set. If the queue was previously empty the number of frames is equal to the number arrived during time t. If the queue had one or more frames, then the number in the queue is equal to the number of frames previously there minus the one frame serviced plus the number that arrived during time t'. The state transition equations are (See Figure M.1):

$$P(m) = P(0)\,Q(m) + \sum_{n=0}^{m} P(n+1)\,R(m-n)$$

The assumption of Poisson arrivals makes it relatively easy to solve this set of equations (m=0, 1, ...). From the definitions of Q(m) and R(m):

$$Q(m) = x^m \exp(-x)/m!$$

$$R(m) = y^m \exp(-y)/m!$$

Multiplying the expression for P(m) by z^m and adding gives the "generating function" p(z):

$$p(z) = P(0) + z\,P(1) + z^2\,P(2) + \ldots$$

$$= \sum_{m=0}^{\infty} P(0)\,Q(m)\,z^m + \sum_{m=0}^{\infty} \sum_{n=0}^{m} P(n+1)\,R(m-n)$$

Q(m) and R(m-n) are replaced by their values in terms of x and y To solve this equation for p(z). The order of summation between n and m is then inverted in the second term of the R.H.S. above. These operations make p(z) appear in the R.H.S. Solving the equation then gives p(z) as a function of x and y. Let:

$$q(z) = \sum_{k=0}^{\infty} Q(k) z^k = \exp - x(1-z)$$

$$r(z) = \sum_{k=0}^{\infty} R(k) z^k = \exp - y\,(1-z)$$

It can be shown that:

$$p(z) = P(0)\;\frac{z q(z) - r(z)}{z - r(z)}$$

The R.H.S. expression is indeterminate for z=1. It can be evaluated by expanding q(z) and r(z) about z=1. This finally gives:

$$P(0) = \frac{(1 - \bar{y})}{(1 + \bar{x} - \bar{y})}$$

where:

$$\bar{x} = \lambda_r\,\bar{t}$$

$$\bar{y} = \lambda_r\,\bar{t}'$$

From the definition of t, t' it can be shown that:

$$\bar{t} = \bar{T} + P(0)\,\bar{t}_{s,k}$$

$$\bar{t}' - \bar{t} = \bar{t}_{s,k}$$

Substituting the expression for P(0) gives, after simplification:

$$P(0) = 1 - \lambda_r \bar{T}$$

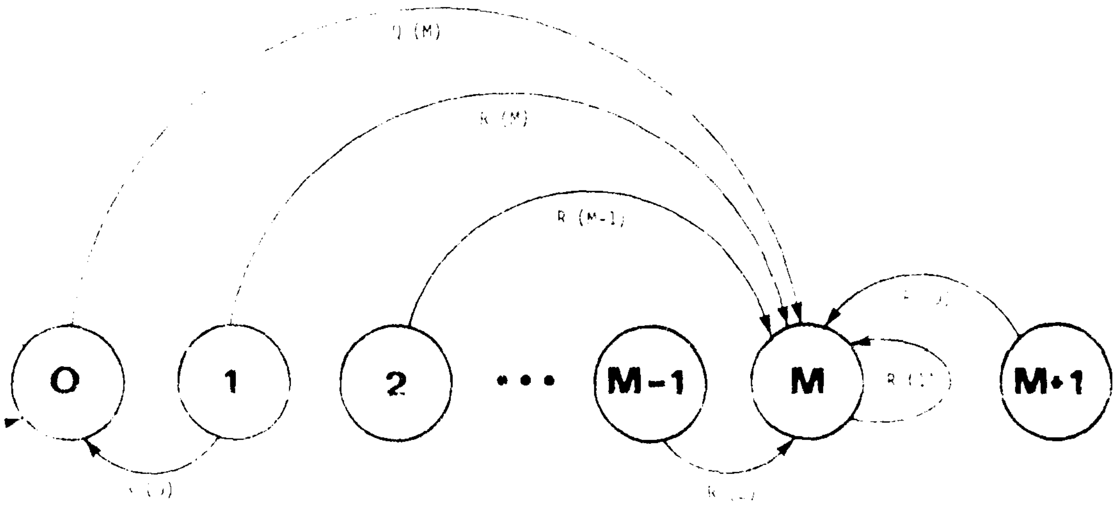
From this equation, the value of $\bar{T}$ can obtained, as follows:

$$\bar{T} = \sum_{r=1}^{m} (1 - p_{r,0}) \bar{t}_{s,r}$$

$$= \bar{t}_{s,1} + \sum_{r=2}^{m} \lambda_r \bar{t}_{s,r} \bar{T}$$

Solving for $\bar{T}$ gives:

$$\bar{T} = \frac{\bar{t}_{s,1}}{(1 - \sum_{r=2}^{m} \lambda_r \bar{t}_{s,r})}$$



State k: k messages waiting in queue when examined by the switch.

$Q(i)$: i messages arrived since queue was last examined by switch and found empty.

$R(i)$: i messages arrived since queue was last examined by switch and found non-empty.

FIGURE M.1: STATE TRANSITION DIAGRAM FOR A QUEUE AT NODAL SWITCH

APPENDIX N

QUEUE AT NADIN SWITCH DUE TO FILE TRANSFERS

When large weather files are transferred from an AWP to the FSDPSs, frames arrive at the NADIN switch faster than they can be retransmitted to concentrators. This appendix calculates: 1) the maximum buffer occupied by frames as they accumulate at the switch, 2) the duration of the busy period created by the file, and 3) the average length of frames arriving from the AWP (this average length is used in delay calculations in Appendix M). Numerical values are obtained in the case of transmission of Surface Observations and Winds Aloft files. These files are the largest weather files and they are also transmitted within 3 minutes of each other when both present (twice a day). With a 4.8 Kbits/seconds trunk line between switches and concentrators, Surface Observations arrive to the switch before the transmission of Winds Aloft file is completed. The busy period duration in that case is the sum of busy periods durations of the two files while the maximum buffer occupancy is less than or equal to the sum of buffer occupancy of the two files.

Assumptions: The analysis assumes that:

- there is no flow control between an AWP and a NADIN switch,
- the interface speed between AWP and NADIN is equal to 9.6 Kbits/sec. (If one of the higher speeds permitted by the EIA-RS-449 Standard is used, the backlog of frames will be higher and almost equal to the file length. The busy period duration will remain the same).
- A frame waiting for the switch attention is not duplicated, even though it is going to 12 FSDPSs, because of multiple addressing. If the internal switch operation requires duplication, then the size of buffer computed here should be multiplied by 12.

Definitions: The busy period model uses the following parameters, some of which have previously been defined and are relisted for convenience:

t: time. $t=0$ is when the first frame of a file transmitted by an AWP reaches the NADIN switch.

λ_1: rate at which an AWP transmits unscheduled FSAS frames to a NADIN switch.

λ_1': rate at which sources other than the AWP transmit frames to an FSDPS via a NADIN switch (e.g., acknowledgements for IFR flight plans sent by an ARTCC).

$\bar{x}_{1,U}$: average length of unscheduled FSAS frames going from an AWP to an FSDPS.

$\bar{x}'_{1,U}$: average length of unscheduled FSAS frames going to an FSDPS from sources other than the AWP.

$m_{a,U}(t)$: number of unscheduled FSAS frames transmitted by an AWP to the NADIN switch during $(0, t)$.

$m'_{a,U}(t)$: number of unscheduled FSAS frames transmitted to the switch by sources other than an AWP during $(0,t)$.

$m_{a,F}(t)$: number of file frames arrived at the switch during $(0, t)$.

$m_a(t)$ $=$ $m_{a,U}(t) + m_{a,F}(t)$: total number of FSAS frames coming from the AWP to the NADIN switch during $(0,t)$.

x_{max}: maximum size of queue at the switch during busy period (in kilobits).

t_F: time between the arrivals to the switch of first and last frames of a file.

t_B: duration of busy period. (period when there is a backlog of FSAS frames at the switch).

C: Capacity of switch to concentrator link in Kbits/s.

C_1: Capacity of AWP to switch link in Kbits/s.

H: Throughput in Kbits/sec of all messages transmitted from NADIN switch to concentrator, except AWP messages.

G: Throughput in Kbits/sec of all messages transmitted from NADIN switch to concentrator, except AWP file messages.

$\bar{x}_{1,AWP}$: average length of FSAS frames coming from the AWP during busy period.

$\bar{x}_1$: average length of FSAS frames going from a NADIN switch to a NADIN concentrator during busy period.

$\bar{x}_k$: average length of a frame from queue k (k=1, 2, . . . m)

L: length of a file frame = maximum length of a frame (2.048 kilobits).

λ_k: average number of frame arrivals from queue k (k=2, . . . m).

<u>Results</u>: The results of a queueing analysis of switch traffic during file transfers are given and interpreted. The proofs are given next.

1) <u>Buffer occupancy</u>: The maximum occupancy of the switch buffer in Kbits during file transfers is given by:

$$x_{max} = L_F \left(1 - \frac{C-H}{C_1}\right) \Big/ \left(1 - \frac{\lambda_1 \bar{x}_{1,U}}{C_1}\right) \qquad \text{N.1}$$

The numerator in the R.H.S. ratio is always less than one, with C-H representing the switch to concentrator capacity available to AWP transmissions concurrently with other messages of total throughput H Kbits/sec. The denominator is also less than one and represents the AWP unscheduled messages, which a file has to contend with for transmission.

If the AWP to switch interface has a speed C_1 higher than 9.6 Kbits/sec, as made possible by the EIA-RS-449 standard, then Equation N.1 shows that x_{max} will be approximately equal to the file length L_F. This is intuitively clear, as a file will then arrive very rapidly at the switch and constitute the bulk of the waiting queue there, since few unscheduled messages will have arrived at the same time.

2) Busy period duration: The duration of the busy period created in NADIN by a file transfer is:

$$t_B = \frac{L_F}{C-G} \qquad \text{N.2}$$

This equation has a straightforward interpretation: the time to transfer a file from start to end along with other messages is equal to the length of the file divided by the capacity of the switch to concentrator line remaining after subtraction of the throughput G of other messages.

3) Average FSAS frame length: The average length of all FSAS frames waiting at the switch for transmission to an FSDPS is given by:

$$\bar{x}_1 = L \left\{ \frac{1 + \lambda'_1 \bar{x}'_{1,U}/C_1}{1 + (\lambda_1 L + \lambda'_1 L - \lambda_1 \bar{x}_{1,U})/C_1} \right\} \qquad \text{N.3}$$

The average length above is close to but less than the full length L of file frames which constitute the majority of frames waiting at the switch. λ_1 and λ'_1 are the rates of unscheduled FSAS frame arrivals from the AWP and other sources, respectively.

Proof of N.1 (queue length)

Equation N.1 is proved in two steps: 1) the value of t_F (time when the last frame of the file arrives at the switch) is obtained and 2) the maximum length of the queue is obtained by assuming it equal to the length of the queue at time t_F. The time t_F is obtained by setting an equilibrium condition on the number of bits arriving at the switch: at time t_F, the number of bits arrived over a line of speed C_1 is equal to the length of the file plus the number of unscheduled bits arrived in time t_F.

$$C_1 t_F = L_F + \lambda_1 \bar{x}_{1,U} t_F$$

Solving for t_F:

$$t_F = \frac{L_F}{C_1 (1 - \lambda_1 \bar{x}_{1,U} / C_1)}$$

The number x(t) of bits in the switch queue is equal to the number of bits arriving over a line of speed C_1, plus bits of frames arriving from all other sources from the AWP minus bits transmitted over a line of speed C. (It is assumed that the size of queue at the onset of a file transmission is negligible):

$$x(t) = C_1 t + (\lambda_1' \bar{x}_{1,U}' + \sum_{k \neq 2} \lambda_k \bar{x}_k) t - Ct$$

$$= (C_1 - C + H) t$$

Substituting the value of t_F in this equation gives x_{max}. Equation N.1 is obtained after rearrangement of terms.

Proof of N.2 (busy period)

Equation N.2 is obtained from a simple equilibrium relation: the number of bits transmitted over a line of capacity C during t_B is equal to the length of the transmitted file plus transmitted bits from all sources during the same period:

$$C t_B = L_F + G t_B$$

Solving for t_B gives Equation N.2.

Proof of N.3 (average length of FSAS frames from all sources)

The average length of FSAS frames (file, AWP unscheduled, other sources unscheduled) is equal to the total number of bits requiring transmission in time t divided by the number of frames transmitted over the same time.

The total number of FSAS bits requiring transmission over the switch to concentrator line in time t is equal to the number of bits coming over the AWP line at speed C_1 plus bits of unscheduled FSAS messages from other sources. Dividing by the total number of frames requiring tranmission gives:

$$\bar{x}_1 = \frac{C_1 t + \sum [illegible] x_{i,U}(t)}{m_a(t) + [illegible]}$$

The number $m_a(t)$ of frames arriving from the AWP to the switch is equal to the number of unscheduled frames plus the number of file frames

$$m_a(t) = m_{a,U}(t) + m_{a,F}(t)$$

The number of unscheduled frames is given by:

$$m_{a,U}(t) [illegible]$$

The number of file frames is equal to the total number of file bits arriving at the switch divided by the length L of a file frame.

$$m_{a,F}(t) = \frac{1}{L}(C_1 t - [illegible] x_{1,U}(t))$$

Substituting the values of $m_a(t)$, $m_{a,U}(t)$ and $m_{a,F}(t)$ in the expression for $\bar{x}_1$ gives N.3.

<u>Calculations:</u> Two files are considered: Winds Aloft and Surface Observations. From Appendix C, these files have lengths of 760 and 930 Kbits, respectively. The length of files is increased to account for link and message overheads. Table 4.6 gives the values of t_B, x_{max} and $\bar{x}_1$

APPENDIX O

DELAY CALCULATIONS

Delay calculations are based on the results obtained in Appendices G, I, J, K, M and N. These calculations are at time quite complex and computer programs were developed to perform them. This appendix illustrates some of the calculations done to evaluate NADIN's performance at times of file transfers: average delays, 90^{th} percentile delays, probability of interframe delays for a message going from a AWP to an FSDPS; the switch and concentrator buffer requirements for a 5% probability of overflow. Calculations assume an overhead of 63 characters in the NADIN message and a 9.6 Kbits/s line speed between switch and concentrator.

The path from AWP to FSDPS consists of links D (AWP to switch), A (switch to concentrator) and G (concentrator to FSDPS). The total average transmission time $\bar{t}_s$ is the sum of transmission times over these three links. The transmission time over each link is equal to the average length of unscheduled AWP messages (1.501 Kbit) divided by the line capacities.

$$\bar{t}_s = 1.501 + \left\{(1/9.6) + (1/9.6) + (1/4.8)\right\} = 0.625 \text{ second}$$

The average waiting time $\bar{t}_w$ is the sum of waiting times over the three links (See Table 4.1).

$$\bar{t}_w = 0.022 + 0.033 + 0.123 = 0.178 \text{ second}$$

The total transmission delay $\bar{t}_q$ is the sum of transmission and waiting time:

$$\bar{t}_q = \bar{t}_s + \bar{t}_w = 0.625 + 0.178 = 0.803$$

To obtain the overall 90^{th} percentile delay, the parameters s_o, over each of the links, are substituted in the equation in Appendix I.

$$s_D = 14.16 \qquad k_D = -5.414$$

s_A = 11.73 $\qquad k_A$ = 5.396

s_G = 4.32 $\qquad k_G$ = 3.017

$$\text{Prob }(t_W > x) < k_D \exp - (s_D x) + k_A \exp - (s_A x) + k_G \exp - (s_G x)$$

The value of x which makes the R.H.S. equal to 0.1 is the 90^{th} percentile waiting delay and is equal to 0.790. The 90^{th} percentile total transmission delay is equal to the 90^{th} percentile waiting delay plus the average transmission time.

$$t_{90} = 0.625 + 0.790$$

$$= 1.415$$

The probability of interframe delay for a message going to a low speed terminal is, from Appendix P:

$$P_{ID} \leq \exp - (t_{OUT} - t_{TSW}) / \bar{t}_{WSW}$$

The probability of interframe delays is checked only for output port line speeds of 1200 bits/s, a case where interframe delays are the most likely to exceed the allow delay because 1200 bits/s is the highest speed for unbuffered terminals. The time t_{OUT} is the time it takes to transmit a frame of 256 characters on the output line, and is 4 times the time it takes to transmit the same frame on the switch to concentrator line. With a switch to concentrator line speed of 9.6 Kbits/s, and the average waiting time $\bar{t}_{WSW}$ given in Table P.3 where no file transfers occur:

$$P_{ID} < \exp - (1.28/0.033) = 1.4 \cdot 10^{-17}$$

That is, the probability of interframe delay is zero for all practical purposes.

<u>Delays of First Priority Messages:</u> No first priority FSAS messages have been identified. If present, they will suffer some delay because they cannot preempt a partially transmitted message going to the same concentrator output port (FSDPS), but

have to wait for the completion of its transmission. (The presence of two physical ports between FSAS and NADIN nodes, one for low priority and the other for high priority messages, can prevent delays of high priority messages). At any rate, there is *only a small probability on an hourly basis that a first priority message will be* preceded by a full 16 frames message going to the same port.

In the analysis made here, only messages of priority one going to other ports are considered. Their approximate average delay is obtained. The waiting time of such messages is equal on the average to half the time it takes to transmit a message of average length over a NADIN link, times the probability that there is a message. This probability is equal to the utilization of the line. For instance, on link A (switch to concentrator), the average waiting time of a first priority message is:

$$t_w \text{ (Pr. 1)} = (0.033 \times 0.276) / 2 = 0.009 \text{ second}$$

The average transmission time of the first priority message is added to its waiting time. The average transmission time is assumed to be constant over all priorities.

$$t_q \text{ (Pr. 1)} = t_s \text{ (Pr. 1)} + t_w \text{ (Pr. 1)}$$

$$= 0.150 + 0.009 = 0.159 \text{ second}$$

Buffer Requirements: The quantities to be determined are the sizes of buffers at the switch and concentrator.

At the concentrator, buffer space is needed for both messages coming from the switch and going to the switch. The size of the buffer is therefore determined by the parameter s_o of the Kingman bound for the switch to concentrator link (See Appendix I). The size of the buffer given in Table 4.5 is such that the probability of overflow is less than 5% (values other than 5% can be substituted in the equations). From Appendix I, the probability of overflow is bounded by

$$P_{of} \leq k_A \exp - (s_A x) + k_B \exp - (s_B x)$$

s_A and s_B are the values of s_o for links A and B, respectively; k_A and k_B are calculated in the same way as for 90th percentile delays. (See Table 4.1)

$x = B/C$, B = buffer size, C = link capacity.

The value of B which makes the R.H.S. of the above equation equal to 5% is 0.62 Kbytes.

The size of the buffer obtained here is based only on the statistics of the queue's build up at the concentrator and does not account for the previously stated need to store one extra frame, in addition to the frame being transmitted on a concentrator output port, if available. Whenever this requirement results in a need for a buffer size larger than the values given in Table 4.5, the largest value must be used as a design constraint.

At the <u>switch</u>, buffer space is needed for messages going to concentrators, as well as to the other switch. Although one message may be going to multiple destinations (e.g., AWP to FSDPS traffic) it is safer to assume that each concentrator creates a need for output buffer space at the switch, independently of other concentrators. The analytical solution to obtain the probability of overflow is different than in the case of a concentrator, because the values of the parameter s_o entering the calculation are all equal. From Appendix I:

$$P_{of} \leq \frac{(s_o x)^m \exp - (s_o x)}{(m-1)!\,(s_o x - m + 1)}$$

The value of x is the same as before, and m is the number of concentrators attached to a switch. The maximum value of m is 12 but is taken to be 18, counting the switch to switch line as two extra concentrators so far as buffer goes (counted twice, once for input and once for output), and counting the concentrator to switch traffic as 2 extra concentrators, buffer-wise.

The values of m, and s_o from Table 4.1, are substituted in the R.H.S. of the above equation to give the required buffer size of 4.62 Kbytes, given in Table 4.5.

In these calculations, for both switches and concentrators, a direct addition of all buffer requirements, instead of the statistical analysis made in Appendix I, would have resulted in a sizable overestimate of buffer requirements.

APPENDIX P

INTERFRAME DELAYS

Unbuffered terminals connected to NADIN must receive frames of a single message continuously because they cannot reassemble a message and present it in its entirety to the user. (The presence of delays between frames is undesirable because it can distract the user or lead him to believe the transmission is over). The unbuffered terminals in NADIN are usually teletypewriters with speeds ranging from 75 baud (Service B) to 1200 baud (AFTN). The continuity of transmissions is easier to achieve for the low speed terminals because NADIN has then plenty of time to bring a new frame to the concentrator while the previous frame is transmitted over the low speed line. As a worse case approach, then, this study only calculates the interframe delays of 1200 baud lines.

The NADIN specification defines the continuity of transmission to be: the availability of successive frames of a message to a terminal with no interruption longer than the time it takes to transmit one character, making the interruption virtually imperceptible to the user.

This study assumes that the NADIN concentrator has enough buffer space to accommodate one frame in addition to the frame currently transmitted. As a result, the switch can start the transmission of a frame even if the preceding frame has not been totally outputted and an interframe delay will occur only if it takes longer for a frame to go from switch to concentrator (including waiting time) than it takes for the preceding frame to be transmitted over the low speed line (see Figure P.1). To give a measure of the likelihood of such an occurrence, consider a 4800 bits/s line between switch and concentrator, 1200 bits/s output line at the concentrator and frames of 256 characters. A frame is transmitted over the output line in 1.7 seconds and over the switch to concentrator link in 0.43 seconds. Therefore, an interframe output delay occurs only if waiting at the switch exceeds 1.27 seconds, usually an unlikely occurrence.

For this reason, the calculation of overall NADIN message delays does not take into account the interframe delays. However, the probability of interframe delays is obtained, both as a measure of soundness for this approximation and as an indication of the performance obtained from NADIN by the low speed terminals. The following is proved below:

Probability of interframe delay $\quad = \quad P_{ID} \leq \exp - (t_{OUT} - t_{TSW}) / \bar{t}_{WSW}$

t_{OUT} is the time to transmit a frame of 256 characters over the output port line.

$\bar{t}_{WSW}$ is the average waiting time at the switch.

t_{TSW} is the time to transmit a frame of 256 characters over the switch to concentrator line.

For instance, with the above example and an average waiting time of 0.3 second at the switch:

$$P_{ID} \leq \exp - (1.27/0.3)$$

$$= 1.5\ \%$$

Proof: P_{ID} is the probability that the waiting time of a frame exceeds the difference between the time it took to transmit the previous frame over the low speed output line and the time it takes to transmit the current frame over the switch to concentrator line. Three observations simplify the calculation:

- The first frame has to be a full frame of 256 characters, otherwise it would not be followed by other frames in the same message.

- The next frame might be either a full or partially full frame, according to whether it was an intermediary frame in the message or the last frame. Assuming that it is a full frame only increases the probability of interframe delay and is therefore on the conservative side.

- The waiting time is a random variable. Because of the nature of NADIN traffic, it generally has a standard deviation smaller than its average, i.e., smaller than the standard deviation of an exponentially distributed random variable having the same average. Assuming that the waiting time is exponentially distributed therefore makes the probability of interframe delay higher and is on the conservative side.

With these three observations, the probability that an interframe delay occurs is equal to the probability that an exponentially distributed random variable with average $\bar{t}_{WSW}$ exceeds the deterministic value $t_{OUT} - t_{TSW}$ and this is given by:

$$P_{ID} = \exp - (t_{OUT} - t_{TSW}) / \bar{t}_{WSW}$$

(The inequality sign in the previous formulation accounts for the conservative assumptions made).

Calculation of Interframe Delay Probabilities: The probabilities of interframe delays are calculated for 1200 baud concentrator output circuits. The probabilities are calculated twice at times of AWP file transfers, for modified and unmodified switch operation, and once at times in between. The columns in Tables P.1 to P.3 are:

- line speed between switches and concentrators (4.8 or 9.6 Kbits/sec),
- number of NADIN overhead characters (20 or 63),
- time to transmit 256 characters on concentrator output circuit (t_{OUT}),
- time to transmit 256 characters on the switch to concentrator circuit (t_{TSW}),
- waiting time at the switches ($\bar{t}_{WSW}$).
- probability of interframe delays.

The last column is obtained using the expression for P_{ID}. Tables P.1 and P.2 are for periods of file transfers, with unmodified and modified switch output queueing procedures. Table P.3 is for periods between file transfers.

Interpretation of Results: Probabilities of interframe delays are very small, the maximum being 2.5% for a 4.8 Kbits/sec line between switch and concentrator and maximum NADIN overhead. The exception of course is when the switch output

queueing procedure is not modified. The frequent occurrence of interframe delays in this case is further evidence of the undesirability of an unmodified switch operation with concentrator to switch line speeds of 4.8 or 9.6 Kbits/sec, a fact already established by the presence of large average message delays in NADIN.

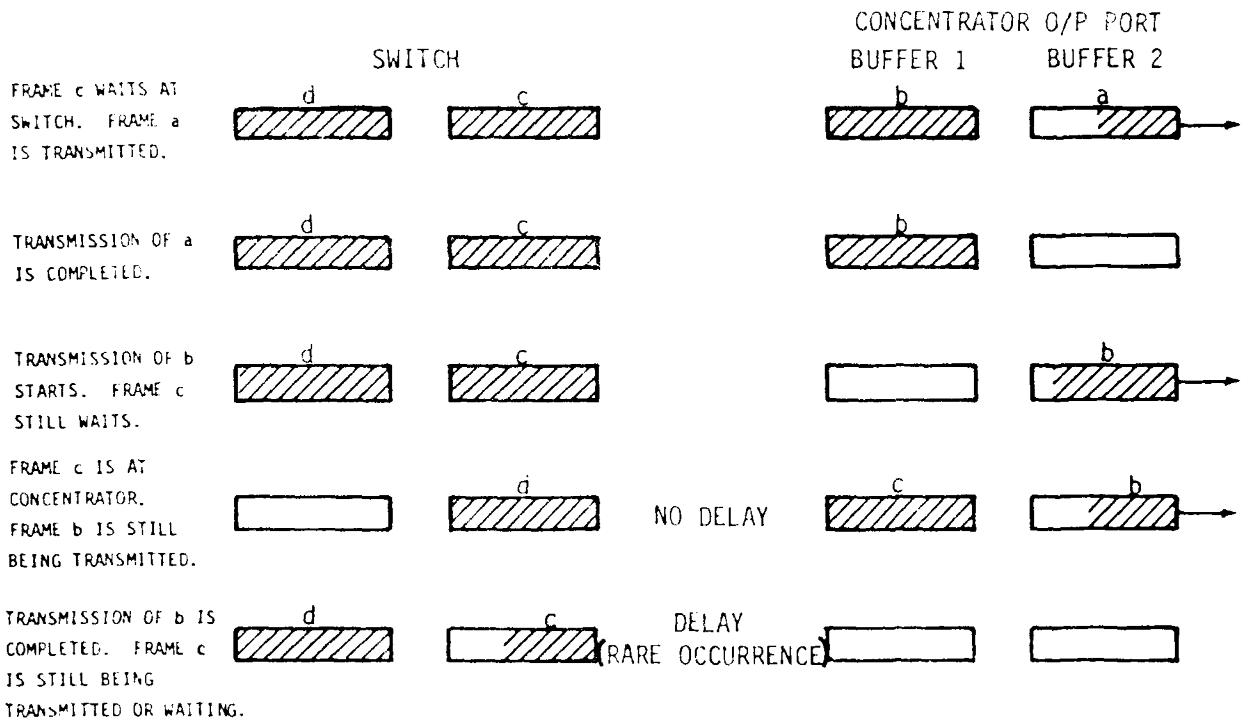


FIGURE P.1: PREVENTION OF INTERFACE DELAYS BY BUFFERING

Line Speed Switch to Concentrator (Kbps)	NADIN overhead (Characters)	Switch to Concentrator Transmission Time (Seconds)	Output Transmission Time (Seconds)	Waiting Time at Switch (Seconds)	Probability of Interframe Delays (%)
4.8	63	0.43	1.71	5.09	77.8
4.8	20	0.43	1.71	4.70	76.2
9.6	63	0.21	1.71	2.22	57.7
9.6	20	0.21	1.71	2.09	54.2

TABLE P.1: PROBABILITIES OF INTERFRAME DELAYS

(File Transfers Period - Unmodified Switch Operation)

Line Speed Switch to Concentrator (Kbps)	NADIN overhead (Characters)	Switch to Concentrator Transmission Time (Seconds)	Output Transmission Time (Seconds)	Waiting Time at Switch (Seconds)	Probability of Interframe Delays (%)
4.8	63	0.43	1.71	0.347	2.50
4.8	20	0.43	1.71	0.316	1.74
9.6	63	0.21	1.71	0.180	0.08
9.6	20	0.21	1.71	0.160	0.03

TABLE P.2: PROBABILITIES OF INTERFRAME DELAYS

(File Transfers Period - Modified Switch Operation)

Line Speed Switch to Concentrator (Kbps)	NADIN overhead (Characters)	Switch to Concentrator Transmission Time (Seconds)	Output Transmission Time (Seconds)	Waiting Time at Switch (Seconds)	Probability of Interframe Delays ([illegible])
4.8	63	0.43	1.71	0.216	0.27
4.8	20	0.43	1.71	0.122	0.003
9.6	63	0.21	1.71	0.033	1.4 E-17
9.6	20	0.21	1.71	0.022	5.4 E-26

TABLE P.3: PROBABILITIES OF INTERFRAME DELAYS

(Normal Period)

APPENDIX Q

FIXED & RECURRING COST OF NADIN COMMUNICATIONS ALTERNATIVES

Q.1 Summary of Calculations

Table Q.1 reflects the results of the calculations presented in this Appendix. Figure Q.1 reflects the Scenario 1 upgrades and serves as a building block for Scenarios 2 and 3 upgrades.

Q.2 Fixed Costs

The fixed costs consist of NADIN concentrator and switch port upgrades and trunk costs encountered in the implementation of the various NADIN alternatives.

Q.2.1 Fixed Port Costs

Port costs, which include both hardware and software costs, are considered one-time costs and are summarized on Table Q.1. Since only one port addition is made at each NADIN location, recurring costs such as additional maintenance, personnel, etc. are considered negligible. It is assumed that the AWP's and FSDPS's will format data in a form acceptable to NADIN. A portion of the NADIN port costs are at both the physical and link control level. The physical level cost is that of the actual mechanical and electrical interface components while the link control costs are firmware/software instruction implementation costs. The additional cost of concentrator/switch overhead instructions associated with routing tables etc., for a particular port addition, will be combined here with a port cost.

Cost for software/firmware implementation is based on a cost per instruction. Experience gained from review of contemporary proposals has shown that $100 per instruction is typical for implementation of communication logic. The exact [illegible] description of the flow control mechanism has not been resolved. For calculation [illegible] it will be assumed to require 200 instructions. Port costs are then summarized [illegible]

AD-A093 293 NETWORK ANALYSIS CORP VIENNA VA F/G 17/2
NATIONAL AIRSPACE DATA INTERCHANGE NETWORK (NADIN) COMMUNICATIO--ETC(U)
NOV 80 DOT-FA79WA-4355
UNCLASSIFIED NAC/FR-303A/01 FAA-RD-80-128 NL

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Function to Be Implemented	No. of Instructions	Cost
Physical Port		\$500/port
Switch Message Processing	400	40,000
Concentrator Message Processing	200	20,000
NADIN switch to AWP Flow Control	200	20,000

Port fixed costs for NADIN can be represented by the following general formula:

$$C_P = 22C_{PP} + C_{SMP} + C_{CMP} + C_{FCL}$$

where the coefficient of 22 represents the 20 CONUS ARTCC's and the two AWP sites, and:

C_P = Total Port Costs
C_{PP} = Cost of Physical Port
C_{SMP} = Cost of Switch Message Processing
C_{CMP} = Cost of Concentrator Message Processing
C_{FCL} = Cost of Flow Control Logic.

FOR SCENARIO'S 1 and 2 these port costs are:

$$C_{P.S1,S2} = 22(500) + 40,000, + 20,000 + 20,000$$

$$C_{P.S1,S2} = 91,000$$

FOR SCENARIO 3 the flow control mechanism is not required and the port costs are:

$$C_{P,S3} = 22(500) + 40,000 + 20,000$$

$$C_{P,S3} = 71,000$$

Q.2.2 Fixed Trunk Costs

There will be zero, small, and moderate fixed trunk cost for SCENARIOS 1, 2, and 3, respectively, as shown on Table 2.1. For SCENARIO 2 the following trunk costs will be incurred:

- upgrade of modem from 4800 to 9600 bps,
- D1 conditioning.

The original cost of the 4800 bps modem will be accounted for in the upgrade to 9600 bps, as it is assumed that the NADIN contract would be amended to incorporate this upgrade. D1 conditioning is included because experience at 9600 bps has shown that besides the guarantees of better signal to noise ratio and less harmonic distortion, the TELCO's usually test the circuits more often and are more responsive to customer complaints. The fixed cost to upgrade one line to 9600 bps is then

$$C_{LU96} = 2\,(C_{M96} - C_{M48}) + C_{D1INSTL}$$

where:

C_{LU96} = fixed cost of upgrade from 4800 to 9600 bps

C_{M48} = cost of 9600 bps modem

C_{M48} = cost of 4800 bps modem

$C_{D1INSTL}$ = cost of D1 conditioning installation

The individual line upgrade fixed cost is then

$$C_{LU96} = 2\,(8500 - 4325) + 163 = 8513$$

<u>The total fixed cost of a SCENARIO 2 trunk upgrade is</u>

$$C_{F,T,S2} = 22\ C_{LU96} = \$187{,}286$$

where the coefficient of 22 accounts for the twenty CONUS NADIN concentrator to switch trunks and two AWP to WMSC trunks and:

$C_{F,T,S2}$ = total fixed cost of trunk upgrade for Scenario 2

For Scenario 3, the cost of the 19.2 kbps trunk upgrade can be analysed by realizing that this line is created by two 9.6 kbps lines and diplexors (as shown on Figure Q.2). The fixed cost of this upgrade is equal to the upgrade from 4.8 to 9.6 kbps plus diplexors, plus one additional trunk or:

$$C_{F,T,S3} = C_{F,T,S2} + \sum_{i=1}^{20} C_{F,T_i} + \sum_{j=1}^{2} C_{F,T_j}$$

where

$C_{F,T,S3}$ = fixed cost of trunk upgrade for Scenario 3

$C_{F,T,S2}$ = fixed cost of trunk upgrade for Scenario 2

C_{F,T_i} = fixed cost of i^{th} 9600 bps trunk from NADIN switch to NADIN concentrator

C_{F,T_j} = fixed cost of the j^{th} 9600 bps trunk from the WMSC to NADIN switch.

Further

$$\left(\sum_{j=1}^{2} C_{F,T_j} + \sum_{i=1}^{20} C_{F,T_i}\right) = 44\ C_{M96} + 22\ C_{D1\text{-}INST} + 44\ C_{ST\text{-}INSTL} + 44\ C_{DPLX}$$

where the only previously undefined parameters are

$C_{ST\text{-}INSTL}$ = cost of service termination installation

C_{DPLX} = cost of diplexor

<u>The total fixed cost of a Scenario 3 trunk upgrade is</u>

$$C_{F,T,S3} = \$600,255$$

The total fixed cost of Sceanrio 2 and 3 are given in Table Q.2.

Q.3 Recurring Costs

Recurring costs of each scenario are shown in Table Q.1. For Scenario 1 the recurring cost is zero while for Scenario 2 the recurring costs is due to a D1 conditioning monthly charge or:

$$C_{R,T,S2} = 22\ C_{D1} = 22(14.65) = 322.30$$

where

$C_{R,T,S2}$ = total monthly recurring cost of trunk upgrade for Scenario 2.

C_{D1} = recurring monthly cost of D1 conditioning

Total recurring trunk costs for Scenario 3 are reflected by:

$$C_{R,T,S3} = 22C_{D1} + 44\ C_{ST} + 0.54 \sum_{k=1}^{22} L_k$$

where

$C_{R,T,S3}$ = total monthly recurring trunk cost of SCENARIO 3

C_{D1} = recurring cost of D1 conditioning

C_{ST} = recurring cost of service termination

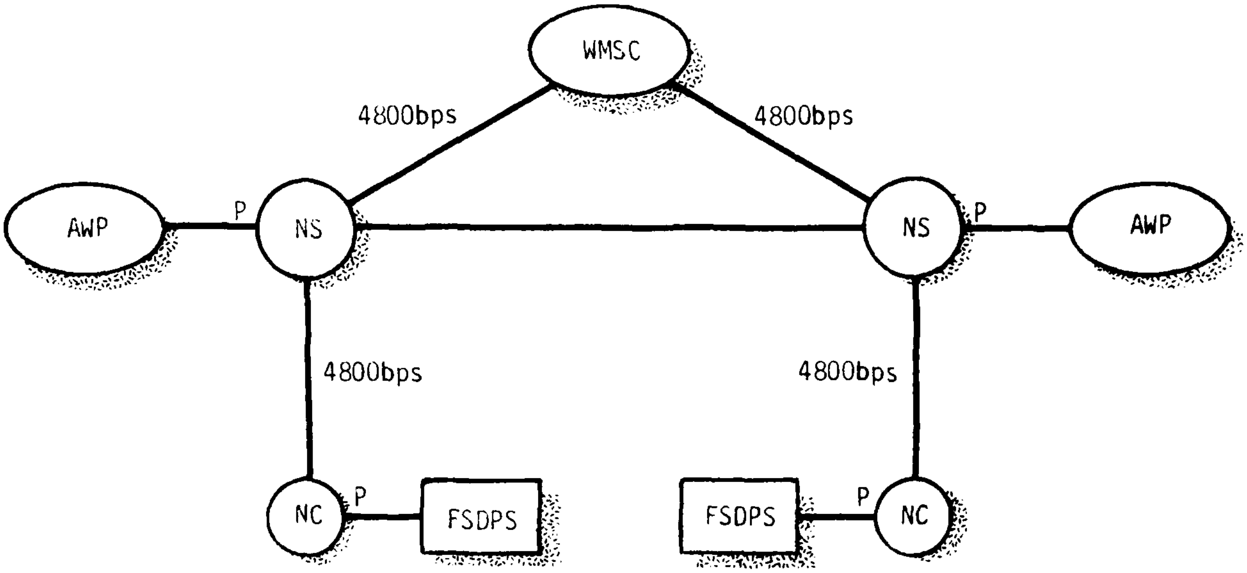
L_k = length in miles of the k^{th} trunk.

The link lengths were determined using NAC's software tool, MIND. The monthly recurring cost is then calculated as

$$C_{R,T,S3} = 22(14.65) + 44\ (43.30) + 0.54(13{,}366)$$

$$= 9445$$

This cost is also shown in Table Q.1.



NADIN UPGRADE
SCENARIO 1

P	=	Port addition
NS	=	NADIN Switch
NC	=	NADIN Concentrator
FSDPS	=	Flight Service Data Processing System
WMSC	=	Weather Message Switching Center
AWP	=	Automated Weather Processor

FIGURE Q.1

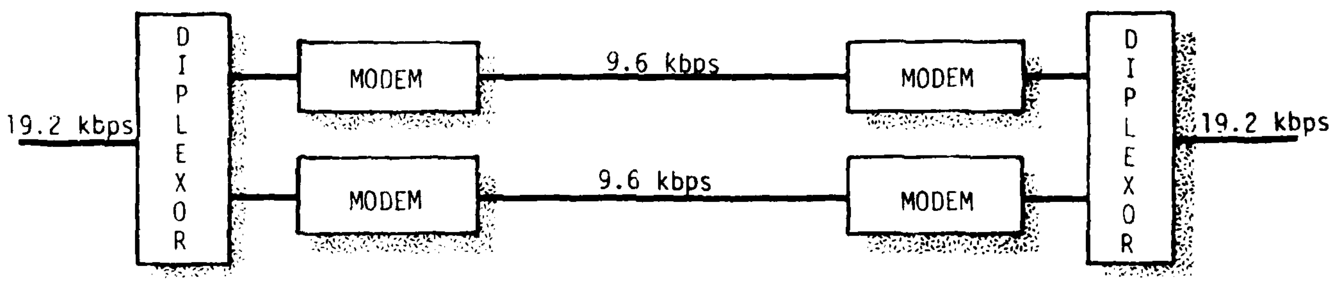


FIGURE Q.2: 19.2 KBPS LINE CONFIGURATION

RECURRING COSTS

VOICE GRADE LINE*	$0.54 per mile per month
SERVICE TERMINATION*	$43.30 per month
D1 CONDITIONING	$14.65 per month
MODEM LEASE (9600) bps)	$249 per month
MODEM LEASE (2400 bps)	$59.55 per month

*TELPAK

ONE TIME COSTS

SERVICE TERMINATION INSTALLATION	$54.15
MODEM INSTALLATION (9600 bps)	$216.00
MODEM INSTALLATION (2400 bps)	$81.20
D1 CONDITIONING INSTALLATION	$163.00
MODEM PURCHASE (9600 bps)	$8500
MODEM PURCHASE (4800 bps)	$4325
DIPLEXOR PURCHASE	$5000

TABLE Q.1: INDIVIDUAL ITEM COSTS

SCENARIO #	DESCRIPTION	FIXED COST			RECURRING COST (MONTHLY) ($)
		PORT COST ($)	TRUNK COST ($)	TOTAL ($)	
SCENARIO 1	NO TRUNK CAPACITY UPGRADE	91,000	0	91,000	0
SCENARIO 2	TRUNK UPGRADE FROM 4800 to 9600 bps	91,000	187,286	278,286	322.30
SCENARIO 3	TRUNK UPGRADE FROM 4800 TO 19,200 bps	71,000	600,255	671,255	9445

TABLE Q.2: NADIN UPGRADE COST SUMMARY

APPENDIX R

FIXED & RECURRING COSTS OF LEASED LINE ALTERNATIVE

R.1 Summary of Calculations

This appendix presents the detailed cost analysis of an alternative that does not include NADIN. This leased line alternative, called the communication contingency plan, has the following cost component summary:

Total Monthly Recurring Cost	$57,083
Total Fixed Costs	$358,693

R.2 Contingency Plan Background

MITRE working paper WP-79W00812 of December 1979 generated alternatives and selected an alternative based on technical merit. NAC assumes that the chosen alternative, referred here as the contingency plan, is capable of meeting the technical requirements of FSAS. This analysis differs from that in the MITRE working paper in the following respects:

- multidrop lines are optimized for least cost,
- modems are considered leased as opposed to purchased (as the contingency plan would be used only while waiting for NADIN's implementation).
- format - the cost components will be formatted to facilitate present worth cost comparison in the next chapter.

R.2.1 Contingency Plan Description

The contingency plan consists of the following major components:

- multidrop 2400 bps lines from the WMSC to FSDPS's,

- point-to-point 9600 bps lines from each AWP to each FSDPS,

- point-to-point 9600 bps lines from each AWP to the WMSC,

- two point-to-point 9600 bps lines from AWP to AWP.

The remaining portion of this chapter is devoted to determination of the fixed and recurring costs of this alternative for the twenty CONUS FSDPS and two AWP sites.

R.3 WMSC Multidrop Lines

Fixed and recurring costs are summarized on Table APS2.1. The minimum cost topology was determined using NAC's software tool, GRINDER, with the following constraints:

- no more than three stations to a line,

- leased modems,

- no conditioning,

- TELPAK tariff.

The resulting optimized network is shown on Figure R.1. The center of the network is the WMSC and the Kansas City FSDPS is connected to the WMSC on a line shared by the Minneopolis FSDPS. The total recurring cost for this network is $6648 per month. This includes service terminations, 2400 bps modem rental, and line mileage charges. The fixed one-time costs consist of the following:

- modem installation,

- service termination installation,

- synchronous port costs,

- WMSC software line handler.

R.4 Point-To-Point Line Costs

Fixed and recurring costs are summarized on Table R.2. All point-to-point lines are 9600 bps and consist of 19 lines from the Atlanta AWP to each FSDPS, 19 lines from the Salt Lake AWP to each FSDPS, 1 line from each AWP to the WMSC, and two point-to-point lines from AWP to AWP. The total is forty-two 9600 bps lines. MIND was used to determine total line mileage.

ITEM	NUMBER	COST	TOTAL
2400 Modem Installation	27	81.20	2,192
Service Termination Inst.	27	54.15	1,462
Synchronous Port Costs	7	500.00	3,500
WMSC Software Line Handler	1000 INSTR.	100/INSTR.	100,000
TOTAL FIXED COSTS			$107,154
TOTAL RECURRING MONTHLY COSTS			$6,648

TABLE R.1: FIXED AND RECURRING MULTIDROP LINE COSTS

ITEM	NO.	UNIT COST	TOTAL
9600 Modem Installation	84	216.00	18,144
D1 Conditioning Instal.	42	163.00	6,846
Service Term. Instal.	84	54.15	4,549
Synchronous Ports	84	500.00	42,000
AWP-AWP	600 INSTR.	100/INSTR	60,000
AWP-FSDPS	600 INSTR.	100/INSTR	60,000
AWP-WMSC	600 INSTR.	100/INSTR	60,000
TOTAL FIXED COSTS			$251,539
9600 bps Modem Lease	84	249.00	20,916
D1 Conditioning	42	14.65	615
Service Termination	84	43.30	3,637
Mileage	46,791	0.54	25,267
TOTAL MONTHLY RECURRING			$50,435

TABLE R.2: FIXED AND RECURRING COST SUMMARY FOR POINT TO POINT LINES

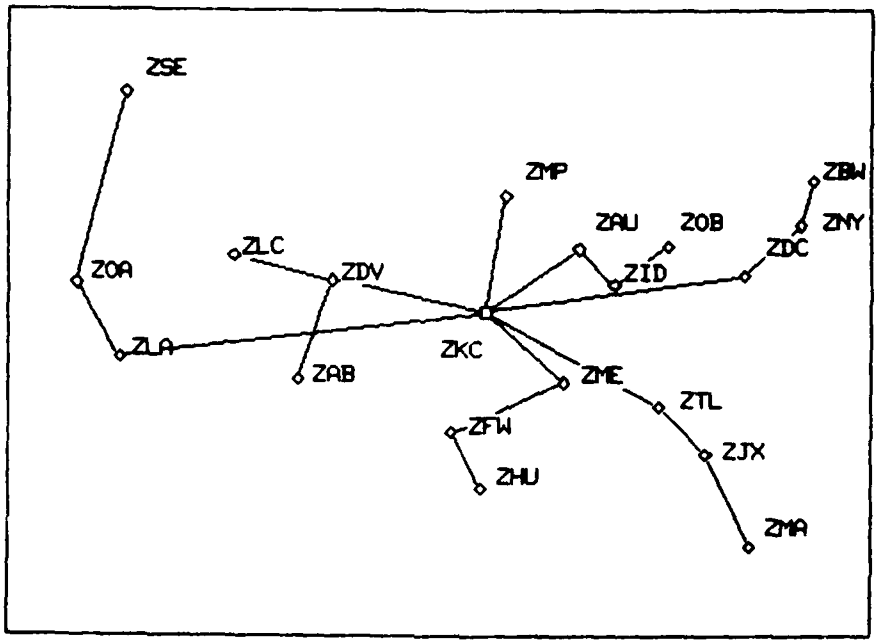


FIGURE R.1: LEAST COST WMSC to FSDPS MULTIDROP LINES

APPENDIX S

PRESENT VALUE CALCULATIONS OF NADIN AND NON-NADIN COMMUNICATIONS ALTERNATIVES

S.1 Summary of Calculations

The present value (PV) calculations for each of the alternatives for one, two, and three year comparisons periods are:

	SCENARIO 1	SCENARIO 2	SCENARIO 3	LEASED LINE ALTERNATIVE
$PV_{1\ yr}$	\$91,000	\$278,286	\$778,684	\$1,007,967
$PV_{2\ yr}$	\$91,000	\$285,285	\$876,348	\$1,598,215
$PV_{3\ yr}$	\$91,000	\$288,314	\$965,132	\$2,134,808

S.2 Discounted Present Value Analysis

The present-value method of comparison consists of reducing all the future differences between alternatives to a single equivalent present sum. In present value comparisons, we must determine a comparison period. Generally, this period is for as long as a cost difference betwen alternatives is expected to exist. The present value after one year is

$$PV_{1yr} = FC + USPVF_{i-n}\ (RC)$$

where

PV_{1yr} = present value after 1 year operation

FC = fixed investment cost

RC = recurring cost

USPVF = uniform series present value factor for payment RC, n times at i interest rate

Here i is considered to be 10% per year or i/12 per month and n=12 months or

$$PV_{1yr} = FC + USPVF_{.1/12-12}(RC)$$

Further,

$$PV_{2yr} = PV_{1yr} + SPPVF_{.1-1}\ USPVF_{.1/12-12}(RC)$$

where

$SPPVF_{.1-1}$ = single payment present value factor brought back 1 year at 10% interest

and lastly,

$$PV_{3yrs} = PV_{2yr} + SPPVF_{.1-2}\ USPVF_{.1/12-12}(RC)$$

where

$SPPVF_{.1-2}$ = single payment present value factor brought back 2 years at 10% interest

These equations reduce to

$$PV_{2yr} = FC + USPVF_{.1/12-12}(RC)(1 + SPPVF_{.1-1})$$

$$PV_{3yr} = FC + USPVF_{.1/12-12}(RC)(1 + SPPVF_{.1-1} + SPPVF_{.1-2})$$

Since $USPVF_{i-n} = \frac{(1+i)^n-1}{i(1+i)^n}$

and $SPPVF_{i-n} = \frac{1}{(1+i)^n}$

then

$USPVF_{.1/12-12} = 11.37421$

$SPPVF_{.1-1} = 0.90909$

$SPPVF_{.1-2} = .82645$

resulting in:

(1) $PV_{1yr} = FC + 11.37421\ RC$

(2) $PV_{2yr} = FC + 21.7144\ RC$

(3) $PV_{3yr} = FC + 31.11461\ RC$.

Fixed and recurring costs of each alternative were substituted into equations (1), (2), and (3) to yield the present value costs for each year.

APPENDIX T

GLOSSARY OF TERMS AND ACRONYMS

A-BDIS Automated Serivce B Data Interchange System

ADCCP Advanced Data Communication Control Procedures. A link level protocol developed by ANSI, ADCCP has all HDLC features plus extended modes of address and control.

AFOS Automated Field Operation and Services.

AFSS Automated Flight Service Station. A flight service station with CRT consoles for graphic display and interactive data retrieval from an FSDPS. (See Appendix B).

AFTN Aeronautical Fixed Telecommunications Network.

ANSI American National Standards Institute.

ARO Airport Reservation Office. Located in Washington, DC.

ARTCC Air Route Traffic Control Center, an FAA facility which provides en route control of the air routes over a major portion of the U.S.; each of the 23 ARTCCs contains a NAS 9020 computer and is scheduled to contain a NADIN concentrator.

ASCII American Standard Code for Information Interchange. Used by FSAS.

ATCSCC Air Traffic Control System Command Center. Located in Washington, DC.

AWP — Aviation weather processor. Central Processing Unit of the FSAS (see Appendix B).

Bit — a binary digit, generally considered to take either the value of 0 or 1.

Byte — a unit of digital data, generally made up of a series of 8 bits. Synonyms: octet, character.

CARF — Central Altitude Reservation Facility

DCE — Data Terminating Circuit Equipment

DTE — Data Terminating Equipment

DUAT — Direct User Access Terminal. A terminal connected to FSDPSs for pilot use.

EFAS — En-route Flight Assistance System

EIA-RS — Electronic Industries Association - Request - Send. A group of interface standards between DCE and DTE. Balanced KS-449 Standard is used for FSAS-NADIN interface.

FDEP — Flight Data Entry and Printout, an FAA communications service used to transmit flight-plan-related messages between remote facilities (TRACONs, towers, etc.) and the NAS 9020 computers.

FSAS — Flight Service Automation System, an FAA program designed to upgrade the dissemination of flight service data (see Appendix A).

FSDPS — Flight Service Data Processing System. Colocated with ARTCCs, the FSDPSs assemble flight related data for general aviation users (see Appendix B).

FSS Flight Service Station. A facility manned by FAA specialists, it provides pilots with weather and flight information and accepts their flight plans (see Appendix A).

Full Duplex telecommunications links that allow simultaneous transmission in two directions.

HDLC *A link level protocol developed by the* International Standards Organization. It has many of ADCCP features.

IFR Instrument Flight Rule. A type of flight controlled by NAS-9020 computers (see also VFR).

Modem modulator/demodulator, a piece of telecommunications equipment that superimposes intelligence onto a signal (modulates) and extracts intelligence from a modulated carrier (demodulates).

MTBF Mean Time Between Failures.

MTTR Mean Time to Repair.

Multipoint a communications link that connects one termination point to several others on a single circuit.

NADIN National Airspace Data Interchange Network, an FAA program to provide a common backbone network for various current and future FAA data communications services.

NFDC National Flight Data Center

NMC National Meteorological Center (in Suitland, MD).

NOTAM Notice to Airmen. Generated by CARF or NFDC.

NWS	National Weather Service
Overhead	those transmissions or portions of transmissions that are not part of the basic information being exchanged; generally this includes control signals or information needed to administer the communications link or direct message processing.
pdf	Probability Density Function (of a random variable).
PDF	Probability Distribution Function. The integral of a pdf.
PIREP	Pilot Report
SA	Surface Observation. A type of weather report.
Service A	Network of 75 baud multipoint lines for weather data collection and dissemination of flight data. Controlled by WMSC.
Service B	Network of 75 baud multipoint lines for collection and dissemination of flight data. Controlled by ABDIS.
TWEB	Transcribed Weather Broadcast.
VFR	Visual Flight Rule. A type of flight where the pilot is responsible for own guidance. The FSS controlling the destination airport is advised of the flight.
WA	Winds Aloft. A bi-diurnal weather report.
WMSC	Weather Message Switching Center. A Phillips DS-714 message switch which controls Service A multipoint lines.
Wx	Weather Radars. Jointly operated by FAA and NWS.

APPENDIX U

REFERENCES

1. FAA-E-2661, "National Airspace Data Interchange Network Specification (NADIN)."

2. FAA-E-2683, "Specification for the Flight Service Information System Automation Program," Volume I. (Hardware)

3. FAA-E-2684, Ibid., Vol. II. (Software)

4. FAA-E-2685, Ibid., Vol. III. (Model I Hardware and Software)

5. FAA-7110.10, "Flight Services Handbook."

6. FAA 7110.80, "Data Communications," January, 1979.

7. FAA Communications System Description, FAA-RD-73-36.

8. FSS-01A, "Master Plan Flight Service Station Automation Program," January, 1978.

9. Preliminary draft of addendum to Reference 8, January, 1980.

10. "FAA Air Traffic Activity, FY-1978," DOT.

11. "Terminal Area Forecasts, 1980-1981," Office of Aviation Policy.

12. "Computer Printout of FSS Forecasted Activity," (preliminary document provided by FAA Office of Aviation Policy).

13. DOD "Flight Information Publication (En Route), IFR-Supplement," (includes maps L-1 to L-26 and H-1 to H-4), November, 1979.

14. NFDC Integration Study, NA-108-008-DOT, October 1978.

15. K. L. Dudkikar and R.G. Nystrom, "FSS Configuration Analysis Study, Configuration Demand Data," MITRE, MTR-6607, Vol. 2 (June 1975).

16. T. B. Fowler, "Data Sources for Flight Service Information System Performance Requirements," MITRE, MTR-7847, (December 1978).

17. R. Kaczmarek and P. McGregor, "The Synthesis of Formal User Requirements," Proceedings of Computer Communication Networks, IEEE Comp. Con. 78: 411-418.

18. I.J. Fredman, "FSS/NADIN Interface and Related Problems," Preliminary draft.

19. J.P. Buzen and P.J. Denning, "Measuring and Calculating Queue Length Distributions," Computer, Vol. 13, No. 4, April 1980, pp 25-31.

20. P.O. Borjesson and C.E.W. Sundberg, "Simple Approximations of the Error Function Q(x) for Communications Applications," IEEE Transactions on Communications, Vol. COM-27, No. 3, March 1979, pp 639-643.

21. L. Kleinrock, "Queueing Systems, Volume I: Theory," Wiley-Interscience, New York, 1975.

22. L. Kleinrock, "Queueing Systems, Volume II: Computer Applications," Wiley-Interscience, New York, 1976.

23. M. Schwartz, "Computer-Communication Network Design and Analysis," Prentice Hall, New Jersey, 1977.

24. Electronic Industries Association, "General Purpose 37-Position and 9-Position Interface for Data Terminal Equipment and Data Circuit Terminating Equipment Employing Serial Binary Data Interchange," EIA-RS-449, November 1977.

25. American National Standard Institute, "Advanced Data Communication Control Procedures (ADCCP)," ANSI X3.66, January 1979.

26. International Civil Aviation Organization, "Aeronautical Telecommunications, Annex 10 to the Convention on International Civil Aviation," Volume II, 3rd Edition, July 1972.

27. P.V.McGregor, "Switch-to-Concentrator Traffic Queueing," NAC.WM.303E.09, July 1980.

28. W. Kassem, "FSAS/NADIN Interface," NAC.WM.303A.04, April 1980.